Christoph Richter

Wood Characteristics

Description, Causes, Prevention, Impact on Use and Technological Adaptation

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Preface

It was 1995, in Dresden, Germany. I had stopped to linger over the display in a bookstore window. Suddenly, my eye caught the cover of a book with two pictures of spruce discs. My curiosity as a forester was piqued. The title read, “Holzfehler – Die Abweichungen von der normalen Beschaffenheit des Holzes” (“*Wood Defects – Deviations from Standard Wood Structure*”), by Hermann Knuchel. I hesitated, because, as far as I knew, the book had been published last century, back in the 1930s. This had to be a new version of the 1934 edition. But why a reprint after 60 years of advances in wood research? Was there no more recent work of its kind?

Investigating further I learned that since Knuchel’s work, many studies had indeed touched on the topic of “wood defects” with some surprising new findings, but none provided such a systematic overview as Knuchel had in his day. “Wood defects” were either the subject of in-depth scientific research, carried out by specialists and published for specialists in scientific journals, or they appeared as subtopics in broader works on wood and wood processing, never as the main subject. Yet, the impact of “wood defects” on price and intended use plays just as important a role in the marketing and manufacturing of wood today as they did back in 1934.

Since that memorable day in front of the bookstore window, I’ve been nurturing a dream to publish a revised study on “wood defects”; at the same time fully aware of the difficult balancing act between covering the topic in sufficient scope and breadth while maintaining the desired technical and scientific depth.

I began by reflecting on the term “wood defect” and the unfortunate way it can stigmatize wood. Can’t the same characteristic that prevents the wood from being used for a specific purpose actually make it suitable for another? Of course. For this reason, going forward I began using the more neutral term “wood characteristics”.

The book begins by discussing the “General factors leading to the formation of wood characteristics”. These influences are responsible for the diversity among the wood characteristics.

The individual characteristics are then categorized into four groups of wood characteristics.

1. *Wood characteristics inherent in a tree’s natural growth*.

   These include changes to a tree’s stem contour, limbiness and anatomical structure.
2. *Biotically induced wood characteristics*.

   Involving all tree internal and external wood characteristics created by micro-organisms, animals and humans or plants.
3. *Abiotic induced wood characteristics*.

   Wood characteristics created by heat, cold, humidity, wind and other external forces.
4. *Crack forms and causes*, where different causes can lead to cracks with similar forms or different forms can have the same causes, are assigned to a separate group of characteristics.

The chapters on the individual characteristics generally cover these five questions:

1. How can the characteristic be described (anamnesis)?
2. What are its causes (diagnosis)?
3. How can characteristics be influenced as the tree grows (prophylaxis)?

4. How does a characteristic effect the various ways the wood is used (impact assessment)?
5. How can technology respond to wood characteristics (treatment)?

The discussion on the individual wood characteristics is supported by corresponding illustrations and a separate section of photographs shows examples of how the characteristics typically appear in nature. The English edition of "Wood Characteristics" maintains the same objective as the 3rd 2010 German edition (Richter 2010).

The book addresses all who work with wood professionally. Foresters, gardeners and arborist want to be able observe a living tree and identify its internal features and the causes of any existing wood characteristics. Based on these findings they can determine how to avoid certain undesirable characteristics, or alternatively how to promote favorable characteristics as the tree and stand grow.

My aim is also to address wood technologists seeking to prevent the impact of adverse wood characteristics on wood processing, or enhance any favorable wood characteristics, as the case may be. Lastly, it gives options for technically adapting, handling and processing wood with specific wood characteristics.

Botanists and dendrologists learn how wood characteristics occur, how they affect living trees and wood products, and how they can be either avoided or encouraged.

New to this English edition is a comparison of wood characteristics found in trees from the boreal, temperate and tropical climate zones. The results show a clear relationship between the effects of sunshine duration, the vertical and horizontal angle of radiation, and crown coverage and the way wood characteristics form.

The influence of wood characteristics on wood quality – compiled in numerous national wood grading standards – is discussed to an extent that clearly shows the connection between wood quality and wood price in the timber industry.

The knowledge gathered in this book is based on the scientific and practical work of foresters, wood technologists and biologists spanning many generations. Without them, but also without the more recent generous support of certain people and institutions, this edition of the book could certainly never have been completed. Therefore I extend my special thanks to Michael Köhl, Institute for World Forestry at the University of Hamburg, for encouraging me to pursue this new edition; Gerald Koch and Hans-Georg Richter (Thünen Institute of Wood Research Hamburg) for supporting me with their wood science expertise.

I would like to thank the German Federal Ministry for Food and Agriculture (BMEL) for providing the material basis for the necessary research in the tropics; the staff at the Centre for Agricultural Research (CELOS), the Stichting voor Bosbeheer en Bostoezicht (SBB) as well as Jos Dennebos, Herman Fräser and Rasdan Jerry (E-Timberindustry) in Surinam, along with my colleagues Bernhard Kenter, Timo Schönfeld and Lars Niemeier (University of Hamburg), who helped make the wood science research in Surinam possible.

My great appreciation is extended to my fellow colleagues from the School of Forestry Management at the Technical University of Dresden, especially Claus-Thomas Bues and Ernst Bäucker, for the photographic material they provided and the insights I gained from them during our numerous professional discussions.

I also sincerely thank Susan J. Ortloff (Oregon, USA) for her sensitive translation. The financial resources for this purpose were mainly provided by the University of Hamburg and the BMEL.

Representative for professional cooperation with Springer-Heidelberg, I thank Christina Eckey (Senior Editor, Plant Sciences) and Anette Lindqvist (Production Coordinator) for edition from "Wood Characteristics".

Last but not least, I thank my wife, Dorothea, for her many years of patient understanding when quite often, instead of spending time with her, I spent it entrenched in this project.

Tharandt, Germany
Summer 2014

Christoph Richter

Contents

Part I Wood, a Truly Remarkable Material

Part II Wood Characteristics Overview

Part III Description of the Wood Characteristics

Part I

Wood, a Truly Remarkable Material

1

The Anatomical Structure of Wood

Wood consists of different types of cells, each with specific functions: transportation, support, and storage. At 20× magnification, it is easy to see how the various cells in a softwood sample together create a distinct structure (Fig. 1.1). The most common cell type, longitudinal tracheids, transports water up the length of the trunk, giving the tree stability. Wood ray tracheids transport nutrients in a radial direction. Longitudinal parenchyma cells store food reserves, while wood ray parenchyma cells support the exchange of material both radially and to neighboring tracheids.

In evolutionarily younger hardwoods, the cells are even more specialized (Fig. 1.2). The vessel cells bind to create highly efficient water pipelines. The narrow-lumined vessel tracheids transport water. The wood fibers mainly provide stability. The longitudinal and pith ray parenchyma cells both transport and store nutrients.

The cells mainly run longitudinally up the length of the tree stem. This leads to anisotropy with differing wood properties in the longitudinal, radial, and tangential directions. This also leads to variations in mechanical stability. As such, the wood's tensile strength is nearly two times higher than its compressive strength. The bending strength, a combination of tensile and compressive strength, lies somewhere in between. There is considerable difference between the strength of the wood running along and against the fibers. Among all tree species, the ratio of tensile strength

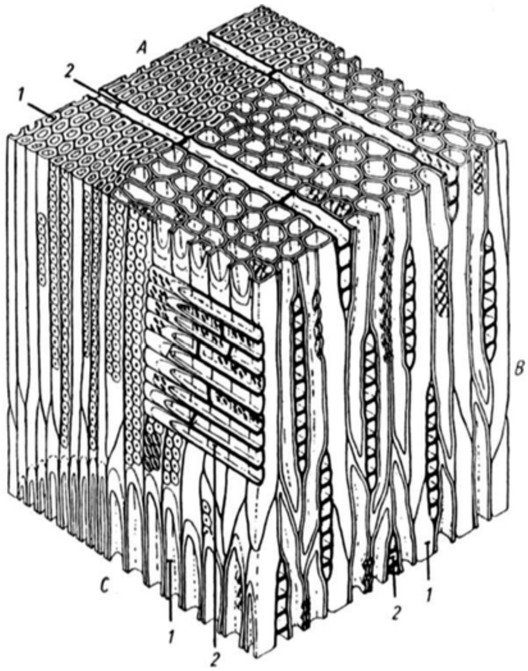

Fig. 1.1 Microscopic structure of softwood. Wagenführ (1966) from Oliva in Tortorelli. *A* Cross section, *1* tracheids, *B* tangential section, *2* wood rays, *C* radial section

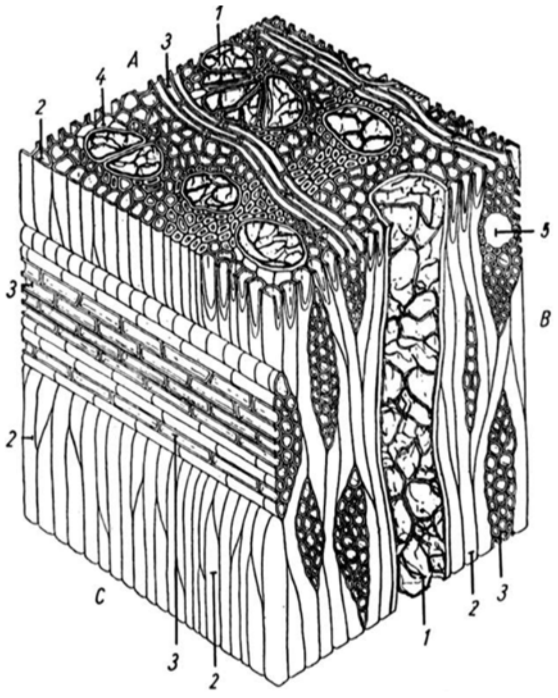

Fig. 1.2 Microscopic structure of hardwood. Wagenführ (1966) from Oliva in Tortorelli. *A* Cross section, *1* vessels with tylosis, *B* tangential section, *2* libriform fibers, *C* radial section, *3* wood rays, *4* longitudinal parenchyma

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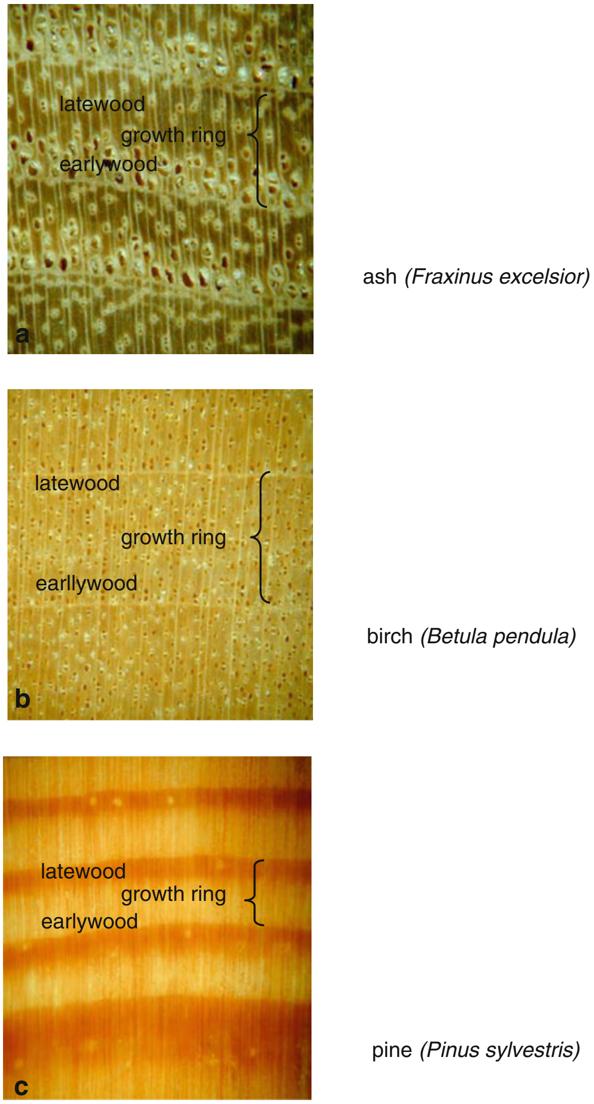

ash *(Fraxinus excelsior)*

birch *(Betula pendula)*

pine *(Pinus sylvestris)*

Fig. 1.3 Cross section of a ring porous (**a**, ash (*Fraxinus excelsior hardwood*)), diffuse porous (**b**, birch (*Betula pendula hardwood*)), and a softwood (**c**, pine (*Pinus sylvestris*)). Enlarged: 1:4 (Photos: E. Bäucker)

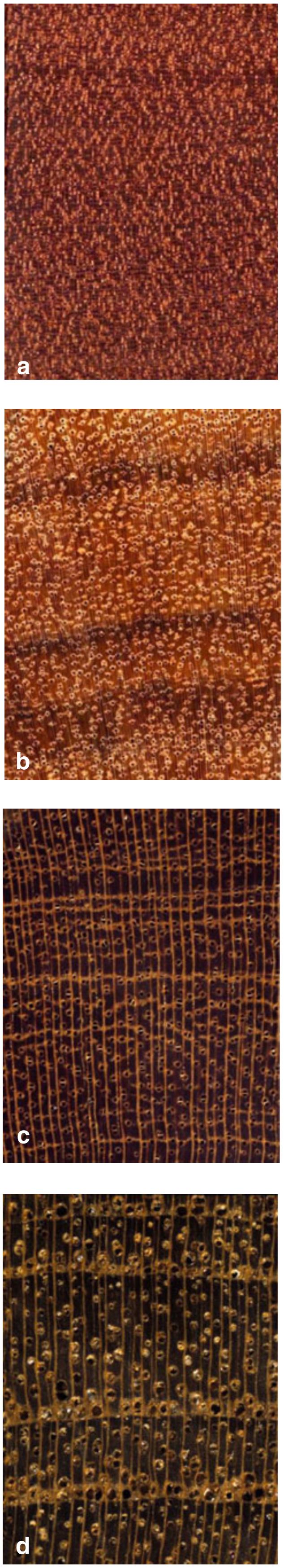

Fig. 1.4 Cross section of tropical woods with variations in increment zone boundaries. Enlarged: 1:10 (Photos: Richter and Oelker (2003). (**a**) Massaranduba (*Manilkara bidentata*): Increment zone visible or only distinguished by density variations in the tissue. (**b**) Cumarú (*Dipteryx odorata*): Increment zone light or indistinguishable boundaries (not to be mistaken for the dark brown stripes). (**c**) Sapeli (*Entandrophragma cylindricum*): Increment zone marked by narrow parenchyma bands. (**d**) Teak (*Tectona grandis*): One of the few ring porous woods in the tropics; increment zone clearly visible by the large pores in the earlywood

along and against the grain is 100:3 … 4, and the ratio of compressive strength along and against the grain is 100:14 … 21 (Niemz 1993).

This anisotropy continues microscopically in the growth rings of trees from temperate regions as new cell layers form during the cambium's vegetative period. Ring-porous hardwood develops wide-lumined vessels at the start of the vegetative period and narrow-lumined vessels later on in the growth process. In much more common diffuse-porous hardwoods, the vessels are smaller, but equally distributed throughout the growth rings. In softwood growth rings, the wide-lumined earlywood tracheids differ abruptly from the narrow-lumined latewood (Fig. 1.3).

In the constantly humid and warm tropical climates, trees typically form increment zones without any significant distinction (Fig. 1.4). Periods of rain or drought, or periods of dormancy or defoliation, appear as increment zone boundaries and are distinguished more or less clearly by variations in cell size, diffused parenchyma bands, and tissue density (Fig. 1.4) (Sachsse 1991). Given the varied growth conditions and the significant variety of species in tropical and subtropical forests, the exact age of tropical trees cannot be determined based on increment zones (Harzmann 1988).

The width and structure of the individual growth ring or increment zone mainly depends on the growth capacity of the specific tree species, nutrient supply, temperature, and precipitation during the vegetation period, as well as on seed years and any damaging events such as drought and insect infestation.

Anyone who has ever chopped wood has taken advantage of this anisotropy. Wood is easiest to cut lengthwise because it splits along the grain. Felled trees split due to the release of internal stress within the wood, starting at the cut and continuing down the length of the stem. Wood rays running in a radial direction also make the wood relatively easy to split from the lateral surface towards the pith. Excellent examples of this are frost cracks on the tree bark. By contrast, wood cannot be split against the grain. The tree's structural building blocks are arranged so that the greatest stability originates in the direction of the trunk's axis.

Wood's significant compression strength and the double as high tensile strength along the fibers enable a tree to hold up under gravity and other external forces. Thus, for example, an ancient spruce (*Picea abies*) growing on a mountaintop has the strength to withstand several tons of snow and ice. Witnessing a tree being hit by a strong gust of wind also offers an excellent example of why a tree needs to have its greatest stability along its fibers.

In tropical primary and secondary forests, heavy crown competition leads to slender, solid wood trees. Forces applied to the foliated crown result in extreme bend and torsion effects, to which the tree reacts by building reaction wood, spiral-grained wood, or uniquely formed stem surfaces.

Only by understanding wood's anatomical structure is it possible to understand why a specific wood characteristic forms and how it affects the way the wood is put to use. Ultimately, every question regarding wood characteristics is actually a matter of wood anatomy. This is true for timber from both temperate zones and the tropics.

Comparing the anisotropic material of wood with other materials clearly shows that the latter have homogeneous microscopic structures (metals, glass) or that the structural elements (chips, fibers in plate materials, and mineral formations in layered rocks such as slate and gneiss) are homogeneously distributed more or less into two levels. This homogeneous structure of amorphous materials, or the layered structure of particle materials or rocks, is often preferred over wood because it is easy to access their material and processing properties. These materials are "predictable."

Nevertheless, clear, defect-free wood expertly used also has excellent performance characteristics. So, for example, the breaking length of wood fibers (length, at which a stick breaks under its own weight) is 15,000 m; in steel St37 with same cross section, it is only 4,700 m (Bosshard 1984a).

Throughout history, the biggest self-supporting vaulted ceilings were made from timber, not concrete. The world record for the heaviest aircraft cargo load was set by the Spruce Goose, a wooden airplane built in the United States to transport troops during the Second World War (Matzek 1985). This record stood for six decades only to be broken by the high-tech Airbus A 380 with a loading capacity of 853 people (Spiegel 2006).

Enthusiasm over wood's truly remarkable properties, however, often fades in practice when a characteristic surfaces making the wood difficult or even impossible to use: A branch within a frame limits the calculated fatigue strength; a batten with missing wood fibers cracks under stress; a stained veneer sheet is unsuitable for high-quality use. Repeatedly, these often unexpected defects threaten to spoil the reputation of wood as a reliable working material. These characteristics hidden inside the wood, or often clearly visible on the stem surface, vary from the tree's "normal" growth or from the "normal" structure of the wood and can significantly influence how the wood is used. Therefore, it is important for anyone working with wood to be familiar with main wood characteristics, how they form, how to prevent them, and how they impact the quality of the end product and the wood's potential technical adaptation.

2

Wood Characteristic or Defect?

The way a tree looks on the surface and its internal features are in fact determined by a set of characteristics. These characteristics form during the natural growth cycle. They include stem shape, branch formation, bark features and the anatomical structure and color of the wood. Throughout the seasons, external events such as temperature variations, rain, snow, wind and lightning also affect the tree. Biotic influences caused by fungal and insect attack, animals, plants, and human activities also play a role.

Surface and internal features make each tree unique. These characteristics are not necessarily defects. Whether they are viewed as (neutral) characteristics or defects is simply a matter of perspective.

Possible approaches are:

From a tree's perspective, a characteristic is only a defect if it significantly influences the tree's natural life expectancy.

Rot can weaken a tree's stability or impair vital functions. A low stem break can kill the trunk with an abrupt loss of crown and foliage (Fig. 2.1). Yet an unusual stem shape, a knot, or obviously the branches, which play an indispensable role in the assimilation process, would not be considered defects.

Fig. 2.1 The fork break in this beech (*Fagus sylvatica*) (*left*) and the deeply imbedded rot in a Gronfolo (*Qualea rosea*) (*right*) in the tropical rain forest are life-threatening defects from the trees' "perspective"

From a woodworker's perspective, the characteristics are defects if they make the wood difficult or impossible to use for a specific purpose (Fig. 2.2).

As a result, a wood characteristic is not a defect if it does not interfere with the wood's intended purpose or if it renders the wood useful for a specific purpose (Fig. 2.3).

Fig. 2.2 Not all branches are equal: This limby spruce will (only) provide lumber full of ingrown and black knots. A branch – at least one with the dead black knot – is seen as a wood defect

Fig. 2.3 A yew (*Taxus*) stem with many small branches (twigs, suckers) can be used to make valuable burl veneer. In this case, the cluster of knots is seen as a desirable wood characteristic

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Fig. 2.4 After 1,000 years of growth, Germany's oldest oak (*Quercus robur*) is beyond any consideration of use (Ivenack, Germany)

Fig. 2.5 In shipbuilding, care was given to use naturally shaped wood for the various parts of a vessel – i.e., branch forks (*red markings*), crooked branches, and curved stems. The photo to the *right* shows frames and stern posts made from an oak tree for the replica of a Viking ship (Roskilde, Denmark)

Fig. 2.6 German Spessart oak *(Quercus)* is valued for its straight, clear stem with regular growth rings and flesh-colored wood – excellent for high-quality furniture and cabinet making

Happy are the ecologists and aesthetes. Where others see wood defects, they see wood characteristics, special traits, unique to a tree and reflecting a synergy among biozones. They accept them as an expression of nature: diversity of shape, originality, vitality, and passage of time (Fig. 2.4).

The following chapters discuss wood from the viewpoint of the woodworker. For the most part, the neutral term "wood characteristic" is used. Only when a specific feature interferes with an intended purpose will the negative term "defect" be used.

Since time immemorial, people have determined the ideal shapes and properties of a tree stem or a piece of wood based on the ultimate end product. In the Stone Ages, wood used to make a spear had to be straight, slender, and elastic, while wood intended for the handle of a flint ax needed to be solid with a hook shape. Carpenters of the Middle Ages preferred oak for beams because wide growth rings made the wood more resistant to bending. In Lapland, people made sturdy sled runners from sickle-shaped root crowns. And well in to the nineteenth century, tree parts selected for their naturally formed shapes were highly prized in shipbuilding (Fig. 2.5). In modern times, given the constant improvements in manufacturing, solid, straight-stemmed, branch-free trees have become the preferred standard. Demands on stem quality are greatest in furniture and cabinet making (Fig. 2.6).

The wood's specific end purpose, therefore, determines whether a wood characteristic is considered a defect, a minor variation, or even a desired feature. Wood has quality when it is suitable for a specific end purpose. Thus, it is essential that a woodworker has a good understanding of the basic wood characteristics. Some wood characteristics are either directly visible or indirectly apparent on a live tree and therefore are given special attention. This is partly necessary because, on the one hand, early identification saves time and energy spent processing unsuitable wood. And on the other hand, recognizing a desirable wood characteristic early on can result in the wood being graded for a much higher quality product. Timber experts and wood technologists have been searching for effective ways to accurately predict the quality of the processed wood based on the quality of the timber. Basic guidelines, such as the Swiss OPS or the Swiss Timber Industry Standards, rate stem quality in the lower portion of the stem (near 8 m high) in three groups, optimal, satisfactory, and poor, and are capable of identifying 10–30 % of the defects found in the logs (Stepien et al. 1998).

More detailed quality classification procedures currently exist which, while quite time consuming (such as laser scanning), also provide a more accurate quality appraisal for veneer or log grade timber (Schute 1972a, b; Richter 2000; Willmann et al. 2001; Schütt et al. (2005)).

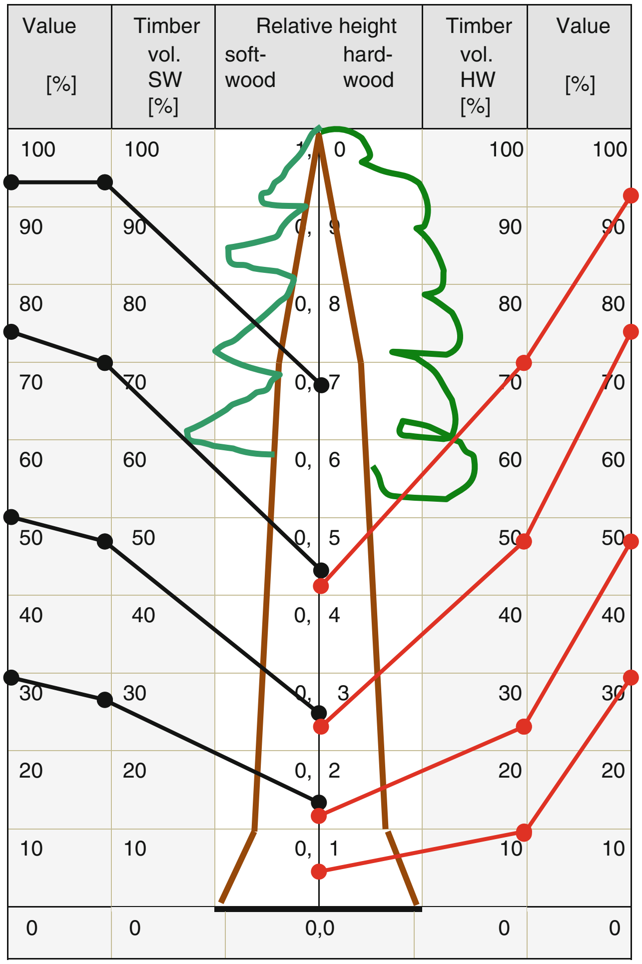


Fig. 2.7 Relationship between volume and value distribution of mature softwood and hardwood trees depending on relative tree height (Richter 2000 after Bachmann 1990)

Stepien et al. (1998) used a multiple regression model to predict the quality of wood from a survey of mature timber with an accuracy of about 60 % for beech, spruce, fir, and pine (*Fagus, Picea, Abies, Pinus*) and about 45 % for larch (*Larix*). The assessment included the ten superficial tree features: branches, suckers, branch scars, bumps, sweep, crook, spiral growth, cracks, necrosis and cancers, (coarse bark only in larch). Only the first 9 m of the stem were assessed in the study, because this section of the stem makes up 50–70 % of the value of softwood and 80–95 % of the value of hardwood, especially beech (Bachmann 1970); compare Fig. 2.7.

Log ends and branch stubs reveal additional, otherwise, hidden characteristics, useful for quality assessment, such as random color variations, decay, pith flecks, growth ring anomalies, reaction wood, and resin ducts. Including as many surface characteristics as possible, the quality of the round timber can be used to predict, with a relatively high degree of accuracy (estimated at around 60–80%), the quality of the future sawn timber or higher-end product. While the cost and expenditure of conducting a quality assessment increases exponentially with the breadth of the survey, failure to conduct a precise quality assessment results in lost revenue. The only way really to mitigate this contradiction is by knowing how to assess wood characteristics.

Timber grading practices vary significantly around the world. The most simplistic method grades logs solely based on length and particularly the average diameter. Today, this method is only used in countries with (alleged) timber surplus and simultaneously low harvest yields. As demand for timber rises, grading standards pay increasingly more attention to features that naturally develop during the course of a tree's life, biotic and abiotic characteristics and crack formations. These grading systems consider characteristics that adversely affect a log's end purpose as defects. Characteristics which allow special usage are considered beneficial. This leads to a differentiated pricing on the international timber market.

In many countries, the requirements for dimension, grade, and end use of commercial timber are set forth in official standards or regulations. Germany followed its own commercial timber grading rules (HKS 2002b) until 2012. The standards recommended for members of the European Union are set forth by the rules on dimension and quality specified by the European Committee for Standardization (CEN) (DIN 1997d, 1998c). There are also bilaterally accepted quality standards established between timber buyers and timber companies that regulate the timber market. As of 2013, German standards follow the framework agreement for sawn timber trade (RVR 2014).

It is impossible to list all the quantitative descriptions given to define individual wood characteristics by the many international grading standards (e.g., Carpenter et al. 1989). Therefore, the following descriptions of specific wood characteristics called or mentioned include extracts from German standards (both past and present), namely, the TGL (TGL 1977b, c), HKS, CEN, and RVR. This seems justified for timber from the temperate latitudes, because Germany's quality standards, established to address a continuously decline in timber supply, date back to the fifteenth century (Willing 1989).

There are three general recommendations for grading tropical timber (Lohmann 2005, p. 87–89):

1. The French grading system, set by the "Association technique Internationale des Bois Tropicaux (ATIBT)," is based on points. Here, a maximum amount of penalty points are assigned to five different quality grades for stems of specific lengths.
2. French classification for "fair merchantable goods" (Loyal et al. Marchande (L & M)). The merchantable timber is classified into five quality grades based on the amount of blemish-free wood, 87.5, 75, 62.5, 100, and 50 %, respectively.
3. English classification according to "fair average quality" (FAQ). The merchantable timber is classified into 5 quality grades based on the amount of blemish-free wood, 100, 90, 80, 70, or 60 %, respectively.

3

General Factors Leading to the Formation of Wood Characteristics

With such variety among wood characteristics, one would think there would also be many different factors leading to their formation. Actually, however, there are only five main "triggers".

The two main "internal" triggers are:

- *Genetic predispositions* and *genetic alterations* in the tree (mutation, genetic defects)
- *Alterations* in the tree's internal *physiological processes* (assimilation, nutrient supply, material transport, chemical reactions, …)

The three main "external" triggers are:

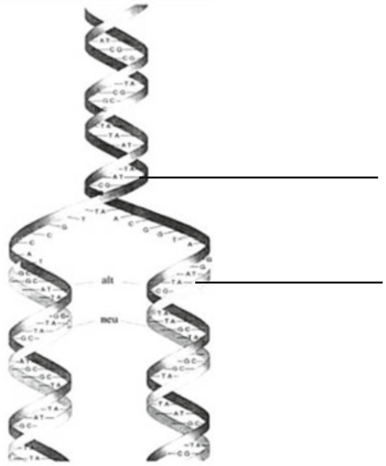
- *Light/radiation* (heliotropism)
- *Mechanical stress* (geotropism, wind, lopsided crown …)
- *Injuries/infections*.

In nature, the effects of these five factors often overlap making a simple cause-effect relationship difficult to identify. Nevertheless, it is important to try to describe how trees mainly react to these five triggering factors before further discussing the individual wood characteristics (formed in response to this "trigger"). These five factors apply, in principle, for trees in the boreal, temperate and tropical zones.

3.1 Genetic Predispositions, Genetic Alterations

All trees grow according to a genetically predetermined design. Hereditary information determines a tree's outward appearance and its internal biochemical processes (Fig. 3.1). If a tree grows under normal site conditions (climate and soil), then woodworkers will usually be satisfied with its morphology. Genetic changes, however, can cause single individuals, or provenances, to deviate from their tree species' "normal form." For example, external characteristics such as the forking tendency among birch (*Betula pendula*) (Fig. 3.2) or the extreme tapering tendency of Engelmann spruce (*Picea engelmannii*) (Fig. 3.3) are genetic. The same applies to fluting in hornbeam (*Carpinus betulus*) (Fig. 3.4) or zwart parelhout (*Aspidosperma excelsum*) (Fig. 3.5), the formation of flanges in elm (*Ulmus laevis*) (Fig. 3.6) and djadidja (*Sclerobium melinonii*) (Fig. 3.7), or burls in spruce (*Picea abies*) (Fig. 3.8) and basralocus (*Dicorynia guianensis*) (Fig. 3.9).

Abrupt changes in a tree's morphology and physiology can also be the result of a *mutation*. A well-known example of a recent, potentially lasting mutation is the corkscrew-



A tree's hereditary information is fixed in its genes, deoxyribonucleic acid molecules (DNA). During replication, the double helix typically divides into two new, identical strands.

Errors occurring in DNA replication can lead to modified growth. If these errors continue on to the offspring, it is called a mutation.

Fig. 3.1 DNA replication (a section of a DNA double helix structure model) (Buchner 2008)

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Fig. 3.2 Genetic tendency to fork in (birch (*Betula pendula*) *left*) or to mono crown (birch (*right*)) (Erz Mountains, Germany)

Fig. 3.3 Genetic tendency to taper in Engelmann spruce (*Picea engelmannii)* (Yukon Territory, Canada)

Fig. 3.4 Fluted hornbeams (*Carpinus betulus*) (Germany)

Fig. 3.5 Fluted witte parelhout (*Aspidosperma marcgrafianum*) (Surinam)

Fig. 3.6 Flanges in a European white elm (*Ulmus laevis)* (Oberlausitz, Germany)

Fig. 3.7 Flanges in djadidja (*Sclerobium melinonii*) (Surinam)

Fig. 3.8 Spruce (*Picea abies*) pimple (hazel growth) (Germany)

Fig. 3.10 Mutation in beech (*Fagus sylvatica, var. tortuosa*) leads to a dwarfed corkscrew shape (Niedersachsen, Germany)

Fig. 3.12 Genetics may be the cause of the abrupt transition from a wide to narrow crown in this spruce (*Picea abies*) (Sweden)

shaped growth of so-called dwarf beech trees (*Fagus sylvatica, var. tortuosa*) (Fig. 3.10). Mutations also account for abnormal cell growth (Fig. 3.11) or can even trigger an abrupt transition from a wide to narrow crown in a spruce tree *(Picea abies)* (Fig. 3.12).

Fig. 3.9 Basralocus (*Dicorynia guianensis*) pimple (hazel growth), (Surinam)

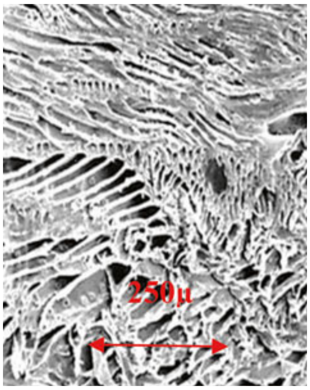


Fig. 3.11 SEM image of abnormally large tracheids in a spruce (*Picea abies*) (Photo: E. Bäucker)

Conclusion: Trees are bound to their genetic specifications. Woodworkers, therefore, must live with their genetic diversity and accept genetic variations in every conceivable form – unless they specifically breed trees to fit their particular needs through *artificial selection* or a *controlled modification of the genetic material*.

3.2 Impact of Physiological Processes Occurring Within the Tree

A tree's vital functions are significantly influenced by the location (climate, soil) on which it grows. The availability of water, nutrients, and light, in particular, determines its internal biochemical processes.

A tree responds to *deficiency symptoms* by altering its growth; for example, if a branch uses up the assimilates it produces itself, instead of exporting them to the stem for radial growth, a moulding will form in the stem section directly below the shade branch (Figs. 3.13 and 3.14).

Air penetration into the stem's interior (branch breakage, internal stem dehydration) can result in oxidative processes

Fig. 3.13 Mouldings in a beech (*Fagus sylvatica*) below a shade branch (Germany)

Fig. 3.15 Beech (*Fagus sylvatica*) with facultative red heartwood, visible as cloud heartwood, and pathological rot (black colored)

Fig. 3.17 Larch (*Larix*) missing pith leading to "moon rings" (Germany)

Fig. 3.19 Oak (*Quercus* ssp.) burl (bud clusters) (Gran Canaria, Spain)

Fig. 3.14 Mouldings in a bolletrie (*Manilkara bidentata*) (Surinam)

Fig. 3.16 Oak (*Quercus robur*) with incomplete pith formation

Fig. 3.18 Moon ring of unknown cause on kopi (*Goupia glabra)* (Surinam)

that lead to facultative heartwood formation. Red heartwood formation is common in beech (Fig. 3.15).

Climatic influences (e.g., early frosts) can prevent cell components from depositing that are needed for pith formation. In such cases, incomplete pith formations (Fig. 3.16), or double sapwood "moon rings" (Fig. 3.17), develop which are distinguishably lighter than the dark heartwood.

The causes of the incomplete heartwood formation in the tropical kopi wood (*Goupia glabra*) shown in Fig. 3.18 are unknown.

Microorganisms can also redirect growth processes in trees to their favor, as easily seen on bumps, burls, and galls (Fig. 3.19).

Conclusion: *A tree can only influence conditions on its growing site over the long term and has no effect on the infectious impact of microorganisms.* Thus, a tree is incapable of preventing any characteristics that they may cause.

Humans can favorably influence a tree's site conditions by improving the soil and through forestry management measures and thereby can gradually alter the physiologically triggered wood characteristics.

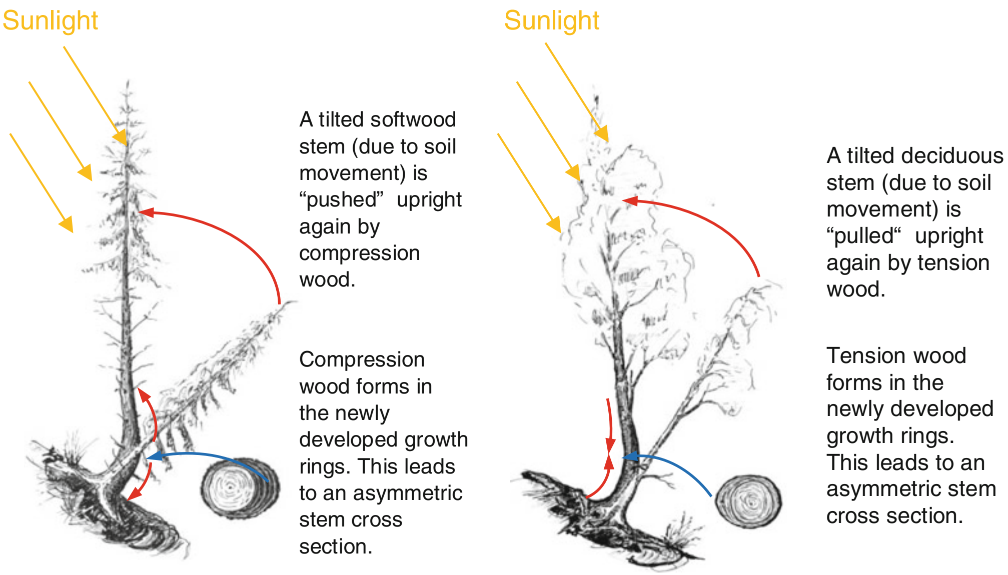
3.3 Light/Radiation

The most important influence on tree growth is the photosynthetic effect of direct and diffused radiation at wavelengths between 400 and 700 nm (Promis 2009). A tree is designed to ensure that its assimilation organs, needles or leaves, receive the maximum amount of sunlight. This constant quest for light is called heliotropism. It affects trees in several ways:

1. Leaves and nonwoody shoots react to light variations throughout the day with growth movements or changes in turgor pressure in the leaf stems (Fig. 3.20).
2. Young, woody shoots can adjust to changes in radiation by reorienting themselves through *growth movements*.
3. "Stronger" branches form reaction wood in response to permanent changes in light, appearing as *compression wood* on the underside of softwood branches and *tension wood* on the upper side of hardwood branches (Fig. 3.21).
4. The stem reacts to permanent changes in sunlight exposure by forming reaction wood in its sapwood over the long term. Growth rings or zones widen on the compression-stressed side of the stem in softwoods or on the tensile-stressed side of the stem in hardwoods (Knigge 1958; Mette 1984) (schematic diagrams Figs. 3.22, 3.40, and 3.41).

Fig. 3.20 Linden (*Tilia*), beech (*Fagus*), and ash (*Fraxinus)* leaves optimally positioned for maximum sunlight exposure (aerial canopy view shortly after foliation) (Hainich, Thuringia, Germany)

Fig. 3.21 Branches, crowns, and stems of hedgerow timber adjust themselves with the aid of reaction wood to receive optimal sunlight exposure (Erz Mountains, Saxony, Germany)



A tilted softwood stem (due to soil movement) is "pushed" upright again by compression wood.

Compression wood forms in the newly developed growth rings. This leads to an asymmetric stem cross section.

A tilted deciduous stem (due to soil movement) is "pulled" upright again by tension wood.

Tension wood forms in the newly developed growth rings. This leads to an asymmetric stem cross section.

Fig. 3.22 Principle of direction change in the stand: reaction wood formation, appears in softwoods (*right*) as compression wood, in hardwoods (*right outside*) as tension wood with simultaneous modifications to the stem cross section