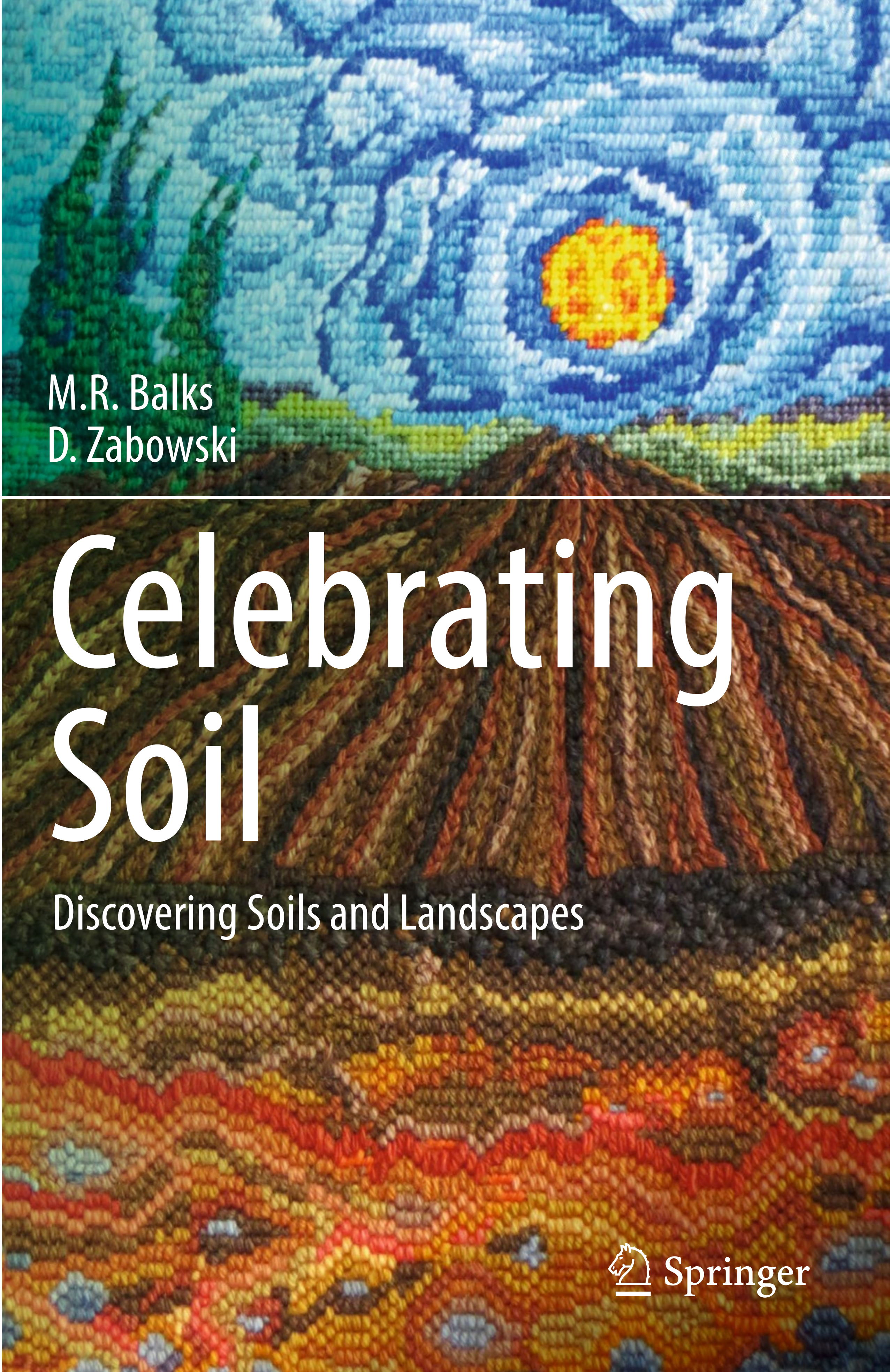

M.R. Balks
D. Zabowski

Celebrating Soil

Discovering Soils and Landscapes

Springer

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Preface

Our objective is to produce a book that celebrates the diversity, importance, and intrinsic beauty of soils around the world and helps the reader to understand the ways that soils are related to the landscapes in which they form and the life that they support. Jock Churchman in 2013 nicely captured our underlying philosophy when he wrote: “Like the Lorax who speak for the trees in Dr Seuss’ wonderful environmental fable, one of the most important roles for *soil scientists* may be to speak for the soil.” We want every person on Earth to appreciate how important our soil resource is. Swaisgood and Sheppard in 2010 suggested that “The gloom and doom niche in conservation is well occupied, …. By contrast the hope niche is relatively open….” Thus we want to give a positive message, rather than the fearful warnings that tend to dominate much of today’s environmental writing.

We want to take our readers on a global journey through soils and landscapes ranging from the Arctic to the Antarctic, sharing the delight of discovery and sense of awe for the amazing variety and processes that soils utilize to support the ecosystems of different landscapes. Exploring the relationships between landscapes and the underlying soils can increase a reader’s understanding of the soils beneath the landscapes in which they live, work, and travel.

A book of this type cannot be comprehensive. The soils and landscapes discussed are ones in which at least one of the authors has first hand experience. By using a wide range of examples, we seek to give some insight into the variety and fascination that is to be found in the study of soils. There are many excellent publications and websites people can go to for more in-depth information. A list of sources and some suggested further reading are included in Appendix 2, as a starting point for the interested person.

The best way to learn and get to know soils is to get out there and get close to the soil. Plant a garden, make a clay sculpture, and enjoy the feel, sight, sound, and smell of the soil in its endless dance with water and life.

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Seattle, WA, USA D. Zabowski

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Special thanks go to our wonderful husbands, Errol Balks and Brandon Cole, who have provided endless support to us as we have pursued our interests in soil science and in preparing this book.

Contents

Chapter 1
Soils in Harmony with the Environment

Productive landscape in the Alsace region of France with cropping on the fertile, near-flat soils in the valley floor, perennial crops of grapes on the lower hill slopes, and forest on the steeper slopes protecting the shallower hill soils from erosion

M.R. Balks, D. Zabowski, *Celebrating Soil*, DOI 10.1007/978-3-319-32684-9_1

Introduction

> "The source and final resting place of everything that grows, soil thus inspires reverence not only in the peasant who derives his daily bread from it, but also in the scientist who contemplates its meaning as the place where life and death meet and exchange vital energies"
>
> Daniel Hillel 1991

Soil, like air and water, is critical to terrestrial life on Earth. Soil underpins human food supply and provides materials on which we build our lives. Soil is out of sight and often out of mind, thus easy to overlook. Yet soil has tremendous variety and intrinsic beauty for those who take time to look (Fig. 1.1).

Soil is the top meter or so of unconsolidated material at the Earth's surface formed where air, water, and life interact with geological materials. Soils contain a memory of events that have shaped the landscape and the environment. With a little knowledge you can look at a soil and understand some of the stories that it has to tell.

Our planet contains a wonderful diversity of landscapes from the cold deserts of Antarctica to the hot deserts of North Africa, the high mountains of the Andes in South America to the rainforests of the Pacific Islands. Each landscape has a different set of soils developed upon it, and within each landscape there is variety and complexity in the soils that form.

Fig. 1.1 Two contrasting soils from opposite ends of the Earth with different stories to tell. (Markers on tapes are 10 cm intervals.) *Left*: an unexpectedly red soil from near the Arctic Circle in Russia reflects the red rocks from which it has formed. The white layer near the surface is the result of acids washed in from the overlying forest vegetation causing the iron-rich red minerals to leach down through the upper part of the soil, leaving only a white sand behind. *Right*: a particularly odoriferous soil formed in penguin guano, and the stones from which penguins make their nests, in Antarctica

Soils are buried treasure and a journey exploring soil provides a wealth of knowledge and experience. There is pleasure to be had in such a treasure hunt: in the food and flowers that grow in soils, in the joy of seeing the colors and patterns that occur, in the sensuous pleasure of working clay in your hand or feeling the warm earth beneath your feet, and in the rich earthy scent of soil after warm rain.

The Environment and Soil

Soils develop in response to, and in harmony with, the environment. Soils are never static as the constituents from which a soil is formed slowly weather and are altered, new minerals are formed, and materials are gradually added or removed. Processes in soils are often imperceptibly slow, by human standards. However soils have time on their side. Occasionally the life of a soil is punctuated by sudden events, such as floods or landslides (or in this day and age attack by bulldozers) that may cause great changes. Plants and animals add, remove, and move materials within soils. Rainwater moving through soil, along with summer heat and winter frost, impacts on the soil and the organisms that dwell in it. The differences between different soils can be explained in terms of a key set of five environmental factors (Fig. 1.2). The five "soil-forming factors" are:

- The geological materials and organic matter that form the *parent materials* from which the soils are derived
- The influence of *topography* or position in the landscape
- The effects of *climate* (primarily rainfall and temperature)
- The impacts of living *organisms*—the myriad plants, animals (including humans), and microbes that live in, or depend on, the soil
- The *time* that the soil has had to develop

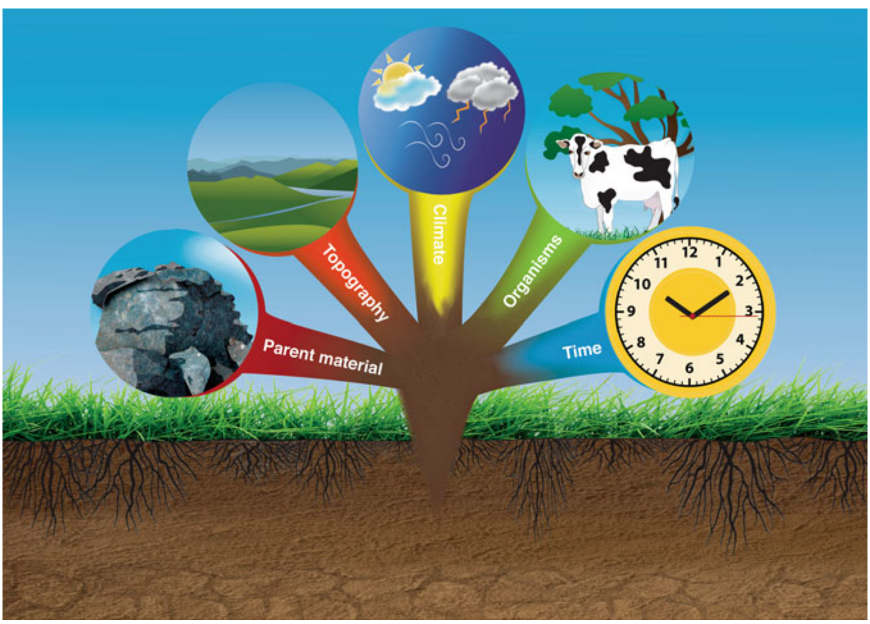

Fig. 1.2 Five environmental elements—the soil-forming factors—interact to create an infinite variety of soils. Soils evolve, over time, in response to the environment

All of the environmental factors interact with one another creating the infinite variety that exists in our soils and the diversity of soils that we find in our landscapes.

In this chapter we will explore each of the soil-forming factors and the variety of soils that evolve in response to variations in the environments to which soils are exposed. Some of the key concepts of the soil and its role in supporting the growing human population are also discussed.

The Underlying Sources of Soil: Parent Materials

Soils are derived from the geological and organic materials in which they form (the parent materials). The diversity of geological materials impacts the resulting soils. Hard, silica-rich rocks, such as quartz sandstones, often weather slowly. Softer, fine-textured rocks, such as weakly cemented mudstones, may weather faster. Different rocks contain different minerals and thus make different chemical elements available to the soil.

Many soils are not formed solely in solid rock, but rather in materials that have been moved around the landscape such as sand dunes; silt, sand, or gravel deposited on a river floodplain; or volcanic material carried through the air. Each material leaves its imprint on the resulting soils. The range of plant nutrients available in a soil mainly depends on the elements that were available from the parent materials. Some rocks, such as limestone, have a high pH, which is inherited by the soil, while others such as a quartz sandstone will usually weather to an acidic (low pH) soil.

Some soils contain minimal rock material as they form from organic, usually plant, material. In swampy, water-saturated environments, dead plant material gradually accumulates, rather than decomposing. Deep deposits of organic matter form peat and the resultant soils tend to be acidic and low in nutrients.

The Russian subarctic boreal forest, where spruce and fir trees dominate the landscape, provides us with an example of the effects of soil parent material on soil properties (Fig. 1.3). The climate is harsh

Fig. 1.3 Soils from the forest zone of northern Russia. Differences between the soils are due to the different parent rocks on which they are formed. *Left*: the landscape near the Pinega River. *Center*: soil formed in sandstone with a typical white layer due to acidified water seeping down from the forest litter removing the reddish-brown iron minerals (podzol). *Right*: soil formed in limestone where the soluble rock disintegrates leaving only an organic matter-rich topsoil over yet to be weathered rock (rendzina). Soil depths are shown in cm

with short, warm summers and long, dark, snow-covered winters. Here we find a surprising diversity of soils, due to the varied underlying geological materials. A soil called a “podzol” with a distinct white, acid-leached layer near the surface is the dominant soil that we expect to form on most parent materials in the Russian forest environment. However, we can contrast the podzol with the neighboring soil formed on limestone rocks where the distinct black topsoil overlies white rock. Limestone is soluble in water and distinctive soils, with a relatively alkaline (high) pH, and minimal B horizon, form on limestone parent materials.

Topography: The Relationship Between Landscape and Soils

The location of a soil within the landscape influences the type of soil that forms (Figs. 1.4 and 1.5). The topography of a site describes the shape of the land including the steepness of the slope, the aspect or direction the slope faces, and the elevation of the site. Understanding the relationship between the topography, of a landscape, and the other factors that influence soils enables soil

Fig. 1.4 A mountainous landscape in Switzerland. Shallow rocky soils occur near the mountaintops. Deeper soils form on eroded materials deposited as fans at the foot of the slopes and on river deposits in the valley floors

Fig. 1.5 A landscape and associated soils in the Waitetuna Valley of New Zealand. Soil *A* is formed on the floodplain deposits of the small stream in the foreground. The soil is fertile due to additions of new silt during regular floods. It is saturated with water in the lower part of the profile due to the proximity of the water table. Soil *B* is on the gently rolling slopes of the lower part of the hills. Here tephra (volcanic ash) from distant eruptions has accumulated over thousands of years giving the soil its distinctive color and excellent soil physical properties. Soil *C* is formed on the steep hills in the middle distance. Here any tephra that falls is eroded off, and so the soil is a product of weathering of the underlying rocks. Soil *C* has a high clay content, is strongly leached, and is not very fertile. Soil *D* is formed on the high slopes of the distant mountains where the altitude leads to cooler temperatures and stronger erosion from high winds and rainfall. The soil is shallow and stony with only stunted shrubs, mosses, and lichens surviving

scientists to develop soil-landscape models that allow them to accurately predict the properties of the soil in different parts of the landscape.

Slope, elevation, and aspect all impact on the climate experienced at a particular site in the landscape. In the Northern Hemisphere, soils on a south-facing slope will usually be drier and warmer than those on a north-facing slope and vice versa in the Southern Hemisphere. The climate is always cooler at higher elevations—for every 100 m gain in altitude, the temperature drops about 1 °C. Higher elevations often experience stronger winds and more intense rainfall. Slope position influences the properties of a soil relative to the other sites around it. A landscape may also have micro-topography such as small mounds or hollows that may only be a meter in diameter, but on which the soils that form are distinctly different from their neighbors.

Topography can influence a variety of soil processes, but often the most important effects are related to water flow, temperature, and soil movement. Soils at the base of a slope or in a valley are more likely to be wetter than those on a ridge or upper slopes due to water moving downhill and persisting at lower sites. If a soil is near the edge of a ridge or located on a steep slope, it is also likely to be shallower (particularly the surface horizons) than a soil near the toe of the slope or in a valley. Soil is more likely to be eroded from ridges and hilltops, and the eroded soil often accumulates near the base of the slope making valley floor and toe-slope soils deeper.

Topography and parent material often change together. For example, a valley may be filled with alluvial deposits from a river, while a hill has soil developing from bedrock. Likewise, topography can influence localized differences in climate, vegetation, and other organisms. Downslope soils are often wetter due to runoff and are more shaded by adjacent hills, so are cooler, and have different vegetation from the warmer, drier, upland soils.

Vegetation often varies within a landscape as it is influenced by the variations in shading, moisture availability, and other factors that are influenced by topography. Vegetation in turn also impacts on the soils that form. At higher altitudes where vegetation struggles to survive in the harsher environment, the absence or limited presence of vegetation means there is less protection of the soil from erosion. Human activity can also strongly impact on vegetation and soils within the landscape. For instance, flatter, low-lying areas are much more likely to be subjected to plowing and establishment of crops, whereas higher steeper slopes are more likely to be left for forests to develop.

Climate: Hot or Cold, Wet or Dry, Soils Respond

Climate influences both temperature and water availability and thus the soil that forms. Temperature controls the rate of chemical reactions, such as the reactions that convert hard rock minerals into soil clays. As a rule of thumb, within the temperature range commonly found in soils, for every 10 °C rise in temperature, the rate of biochemical reactions will double. Thus soil chemical weathering operates faster in warmer climates as do most biological processes. Temperature extremes, both hot and cold, limit the ability of plants, animals, and most microbes to survive in the soil.

Water is critical to many soil processes. Often the chemical reactions that break down rock minerals involve reactions with water. Water is vital to the growth and survival of plants and soil organisms. Water also influences soil physical processes. Much soil erosion is facilitated by water. When water freezes in the soil, it expands forcing soil aggregates apart and helping to break up rocks. Nutrients in the soil can dissolve in water and can then be taken up by plant roots or washed down, through the soil, into the groundwater and then ultimately into rivers and the sea, thus making the sea salty.

The broad climate zones of the planet (Fig. 1.6) are generally associated with a suite of soil properties. In the warm, wet tropics, soils tend to weather strongly to deep, relatively infertile, red-colored, clay-rich profiles. In the low-latitude deserts, such as the Sahara, water limits plant growth and soil

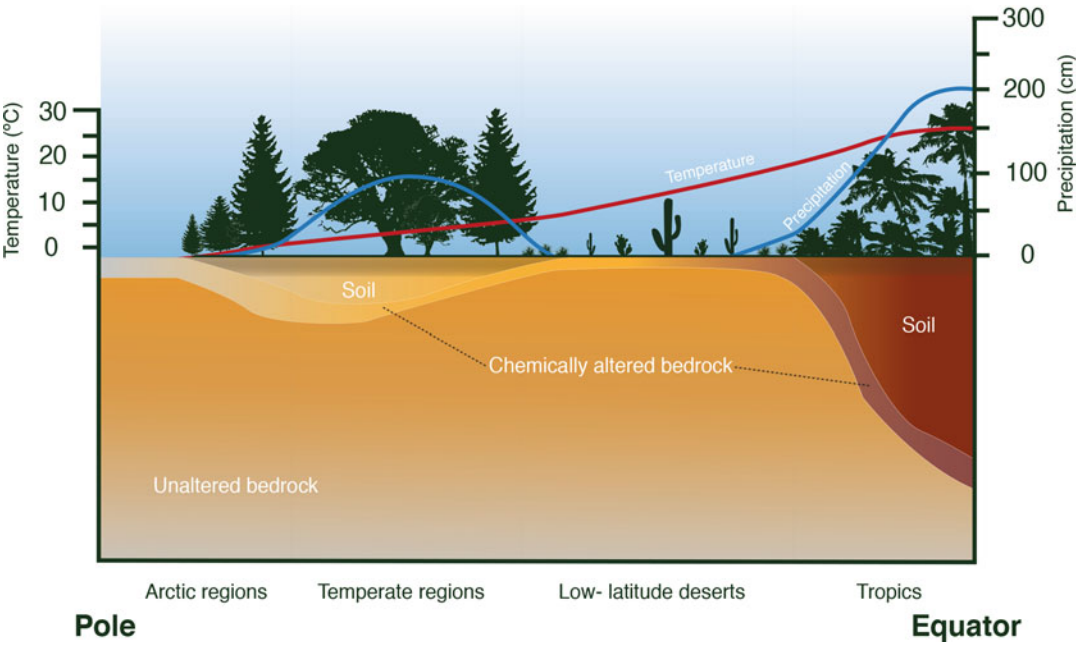

Fig. 1.6 The pattern of climate and depth of weathering and soil development from the equator to the poles

Fig. 1.7 A deep, red-weathered soil from the warm wet tropical environment of Thailand supports good crop growth when plant nutrients are added

development, resulting in sandy desert environments. In temperate regions moderate soil development supports productive grasslands and forestlands. In the cold desert of the Antarctic, chemical weathering is limited, and soils mainly comprise gravelly sandy materials broken down from solid rocks by the actions of glaciers, wind abrasion, and water freezing and thawing.

The tropical heat of Thailand provides us with an example of the effects of a warm wet environment on soil development (Fig. 1.7). In tropical regions the weathering of soil materials to form clay extends tens of meters beneath the soil surface. However, tropical soils are often poor in plant

Fig. 1.8 A relatively shallow stony soil from the cold desert of the Wright Valley in Antarctica where life is generally limited to microbes, and soils contain minimal clay or organic matter

nutrients as soluble products of weathering (such as potassium and magnesium which are important plant nutrients) have been leached from the soil by the frequent heavy rainfalls. In the warm wet environment, organic matter from dead plants or animals is quickly decomposed, and the nutrients are taken up by the vegetation or leached away by the rain. Thus in tropical forests, the vegetation, rather than the soil, contains most of the plant nutrients. If tropical forests are removed, the nutrients are often lost with them, leaving a further impoverished soil environment.

In contrast, in the Antarctic Dry Valleys, we find some of the coldest, driest soils on Earth (Fig. 1.8). Here chemical weathering proceeds extremely slowly with just a faint tinge of rust color showing that some iron oxides have formed. The soil is dominated by rocks, gravel, and sand that have formed due to physical abrasion of the rock materials when they were moved and deposited by glacier ice. Soils in the Dry Valleys contain a diversity of cold-tolerant microbes, but no higher plants survive, so organic matter in the soils is negligible.

Living Creatures: Influence on the Soils on Which They Depend

A myriad of organisms live in the soil and all terrestrial life ultimately derives its sustenance from the soil. In the natural world, when an organism dies, its remains are broken down by soil microbes and thus its energy and nutrients are harnessed to support a new generation of life.

A teaspoon of topsoil may contain as much as 100 billion bacteria and 15 km of fungal hyphae along with a host of other microbes, ranging from tiny worms, called nematodes, to microscopic insects such as springtails (Fig. 1.9). Larger microbes such as protozoa dine on the bacteria, and tiny animals such as rotifers may in turn eat the protozoa. Thus the food chain begins. Many soil microbes dine on dead plant and animal matter and, in the process, release nutrients. Plants can then take up the nutrients. Thus the activity of soil microbes provides a vital recycling service that underpins the whole food chain.

Many larger insects and animals make their home in the soil. For example, earthworms consume organic matter and eat soil mineral material with it; after they digest the lot, their waste is often

Fig. 1.9 Soil organisms. *Top*: a scanning electron microscope photo allows us to see soil microbes. The shell creature is a "testate amoebae," a soil protozoa that eats bacteria. The tiny rectangular shapes below the protozoan are bacteria that, along with the slime they produce, are coating the soil surface. (The dotted scale is 12/1000 s of a mm long.) *Middle*: earthworms are a common soil inhabitant. *Bottom:* a termite mound in Australia demonstrates the ability of some insects to move soil materials

deposited as worm casts at the soil surface. Worms also create burrows that allow air and water to move readily and rapidly through the soil. Termites, wasps, ants, moles, and rabbits are all examples of creatures that move soil material around in order to create a suitable home.

As plants grow and die, they provide a vital source of organic matter for soils. Some plants provide surface leaf litter, that is, a source of nutrients and also a protective layer that accommodates many small insects and microbes, as well as helping capture moisture and reducing soil erosion. Plant roots explore deep into the soil, extracting moisture and nutrients and helping hold the soil together—thus also preventing soil erosion. Plants often produce acids that are washed into the soil and impact on many of the chemical processes that occur in soils. In saturated environments, when plants die, microbes may not readily break down the organic material, and thus it gradually accumulates to form organic soils known as "peat."

We should remember too that of all the organisms that impact on soils, humans are capable of some of the greatest impacts.

Time: It Takes Time for a Soil to Develop

As the saying goes "all good things take time" and forming a soil can be a very slow process. Soils progress from new material being exposed at the soil surface through to development of a strong and productive soil over thousands of years. Eventually the weathering processes continue until a soil becomes old, weary, leached of nutrients, and weathered to clay. In many parts of the planet, soils are reinvigorated from time to time by processes such as erosion or deposition of new materials. In the relatively rare cases where land surfaces have remained stable for millions of years, the ancient soils that form are beautiful and they contain a record of the past.

The rate that a soil develops depends on other environmental factors such as climate and parent materials. In the extreme cold and dry environment of Antarctica, soil processes operate exceptionally slowly. However some Antarctic land surfaces are thought to be millions of years old, and so even exceedingly slow soil development can proceed to form distinctive soils. In warm wet climates where vegetation thrives, a soil will form relatively quickly, especially if the substrate is an unconsolidated material such as silt or sand.

The youngest soils, often referred to as "recent soils," are formed on newly deposited materials and show only the very first stages of soil development. New materials may include recently deposited lavas (Fig. 1.10), silt deposited by rivers on floodplains, and surfaces newly exposed to soil processes as a result of erosion and removal of the preexisting soil.

Fig. 1.10 On lava erupted in Hawaii 40 years ago, the soil is only just beginning to form. In deeper cracks in the rock, windblown leaf litter has accumulated, providing some organic material. Hardy plants find a niche in the cracks where moisture can be trapped, and there is some protection from the scorching heat of sun on the black rock surface. As more plants colonize the surface, they help enhance the rock-weathering process, and so, over thousands of years, a new soil will form

Fig. 1.11 Shallow sandy soils formed on ancient rocks in Australia in an arid environment where weathered soil material has been periodically removed by erosion

Ancient rock surfaces in Australia have been exposed to many cycles of weathering and erosion. The rocks exposed in the Karijini National Park in Western Australia were formed in the sea about 2.5 billion years ago, and the present-day land surface was formed over the last few tens of millions of years (Fig. 1.11). Ongoing erosion and a harsh, hot, dry climate means that even though the rocks and landforms are ancient, the soils, although much older than those in many parts of the world, are often relatively thin and stony.

Looking Deeper: Understanding the Soil Profile

Factors that affect soil such as climate and organisms have more impact near the surface of the earth. Thus, soil materials weather and change more quickly at the top. To really understand a soil, you should look at a cross section from the ground surface right down to where the original geological material has not been greatly altered. The vertical cross section of soil is called a “soil profile.” Looking at a soil profile, you will see that changes in color and other soil properties, such as clay content, occur down the profile. Such changes help us distinguish different zones within the soil which are called “soil horizons” (Fig. 1.12). There are five main soil horizons. A, B, and C horizons can be found in almost any type of soil. The O and E horizons are more common in forested or wetland soils.

A Horizons
A horizons are what most people call top-soil. A horizons have a dark colour due to the accumulation of decomposed organic matter. The A horizon is usually the most fertile part of the soil and it is also typically the most weathered and altered soil if you compare it to the rocky material the soil is developing in.

B horizons
B horizons are often called subsoil. B horizons are not as enriched in organic matter as A horizons, but the parent material has been altered so much that it no longer looks like the original rock material. Usually a B horizon has paler colours; often yellow, orange, or reddish hues. Another characteristic that distinguishes a B horizon is that particles are often clumped into aggregates. B horizons may also have accumulations of materials such as salts, oxides, or clays. B horizons are not usually as fertile as A horizons.

C horizons
C horizons are the underlying, relatively unaltered, rock or parent materials. Soils that are young (or have barely begun to form) may have only a C horizon. If you look closely at a C horizon, you will see bare, unweathered, rock material.

O horizons
Organic matter that accumulates at the soil surface, from falling litter from trees or deposition of decaying vegetation creates an O horizon. The O horizon is composed entirely of organic matter without any mineral soil. O horizons can range from fresh plant material, such as leaves and branches, to well-decomposed and unrecognizable humus.

E horizons
A soil horizon, just below the topsoil, that is white or pale grey may be an E horizon. E horizons have lost organic matter, iron oxides or other materials that give the soil colour, through leaching. E horizons are often found beneath O horizons, but may be underneath an A horizon as well.

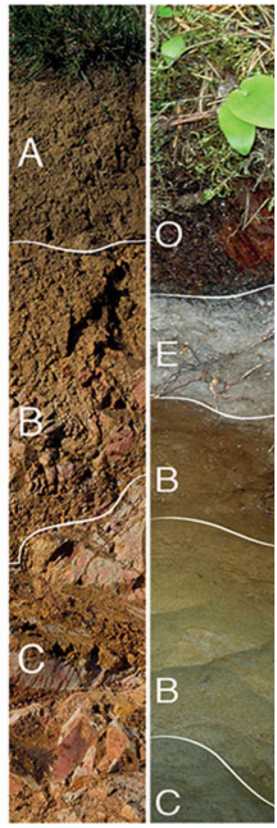

Fig. 1.12 Soil profiles with horizons marked. *Left*: a simple soil profile containing A, B, and C horizons. *Right*: a more complex soil profile with O, E, and two B horizons above a C horizon

Celebrating Soils in Harmony with the Environment

Every soil, if studied carefully, like every human face, has etched into it the effects of the environment in which it has developed. Most soils are old, much older than our human timescales allow us to readily appreciate. Some soils have endured through, and often been profoundly altered by, past climate changes. The last glaciation that occurred between about 100,000 and 15,000 years ago had major impacts on the soils and landscapes of all the higher latitude lands such as Europe and North America. Our soils have, over time, been subjected to effects of falling and rising sea levels, the arrival of humans, changes in the vegetation cover, erosion and deposition of materials, and in many cases the development of human agriculture. The soil is quietly resilient, and for all the changes that have occurred, it continues to support the myriad life-forms that make up our ecosystems. It is interesting to take but one example of a soil and look carefully to see what it can tell us (Fig. 1.13).

Fig. 1.13 This soil from Tasmania, in Australia, tells of gradual earth movement on a hill slope which humans have periodically impacted over thousands of years. The soil profile was exposed as the result of a landslide that removed the soil that was adjacent to it. The presence of "improved" pasture grasses tells of human actions—repeated fire may have removed the previous forest vegetation. Fertilizer, along with grass seed, has been added. Roots are evident in the top, overhanging edge of the soil—some left hanging as the soil has eroded away from beneath them. Small, hard, sharp-edged stones have been found in the surface of these soils, possibly left behind by aboriginal peoples long before the arrival of European settlers in the region. The cracks tell of drying clay hint at occasional wet periods when water moves down the cracks bringing the gray sandy surface soil with it until the wetted soil swells again and the cracks are filled. The soil is on a slope and has formed from material that has gradually moved downslope. Within the subsoil, below this picture, there is evidence of a buried soil that once formed the land surface at this site

Chapter 2
Soils Born of Fire

Erupting volcanoes create new land surfaces on which new soils develop, Kiluaea, Hawaii

M.R. Balks, D. Zabowski, *Celebrating Soil*, DOI 10.1007/978-3-319-32684-9_2

Introduction

> "Nature is often hidden, sometimes overcome, seldom extinguished"
>
> Francis Bacon, 1625

Volcanoes are one of Earth's most fearsome exhibitions of power. Erupted lavas and tephra (volcanic ash) are a source of materials that weather to form new, and often exceptionally productive, soils.

Volcanoes create and shape landscapes. Whether building huge shield volcanoes, such as the Hawaiian Islands, or coating landscapes with far-flung pumice or tephra from explosive eruptions, such as Crater Lake in Oregon, USA, the effects, and products, of volcanic eruptions are a source of fascination.

People who live in the paths of volcanic eruptions understand the terror of blasts of hot fiery materials or mudflows that extend far beyond the confines of the volcano itself. Mud falling on homes and fields, the inconvenience of airplane flights canceled, and the surreal beauty of bright red sunsets all occur due to volcanic ash, aerosols, and gases, impacting audiences at ever greater distances from the source.

Soils in regions impacted by fallout from volcanic activity contain a memory of the eruptions that have occurred (Fig. 2.1). Burial by volcanic deposits may capture moments in time that are a record of life's tragedy, for instance, the chilling images of people in Pompey, Italy, buried by the eruption from Vesuvius in 79 AD.

Fig. 2.1 This soil, formed in volcanic deposits in the Gunma prefecture of Japan, contains the memory of a long history of volcanic activity. The topsoil includes scoria from the 1783 eruption of Mt. Asama, some 80 km away. The white pumice was erupted from Mt. Haruna about 1400 years ago. The dark-colored buried topsoil contains evidence of cultivation having occurred at this site about 1500 years ago prior to the pumice eruption. The bright brown gravelly layer toward the base of the profile was erupted from Mt. Asama about 15,000 years ago. Below the bottom of this picture is a distinctive tephra erupted from the Aira caldera, about 1000 km away, about 30,000 years ago