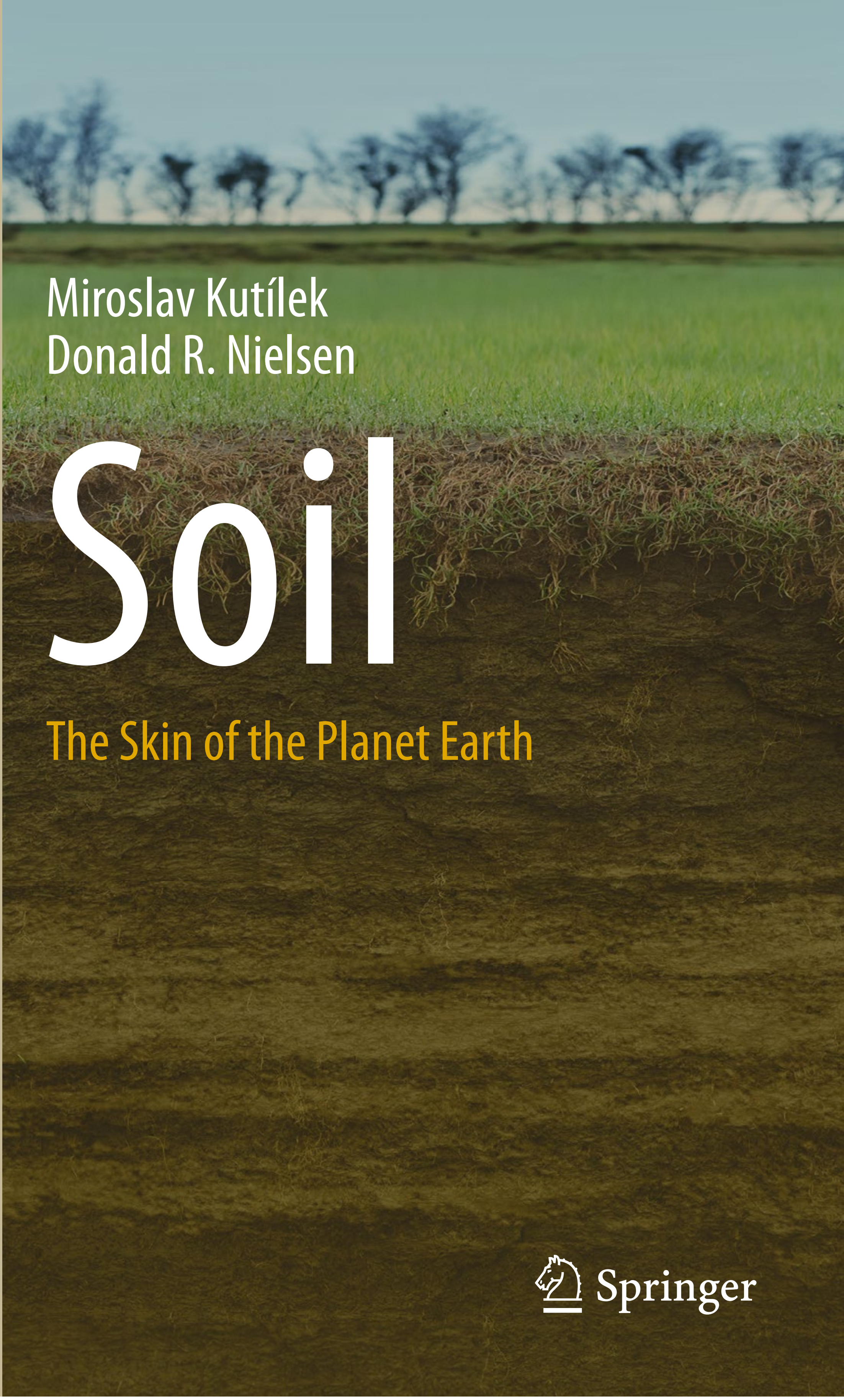

Miroslav Kutílek
Donald R. Nielsen

Soil

The Skin of the Planet Earth

Springer

Soil: The Skin of the Planet Earth

Miroslav Kutílek • Donald R. Nielsen

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Chapter 1
Omnipresent Soils

Knowledge of our *Homo sapiens* existence is restricted to a tiny patch of both space and time in the cosmic infinity. In spite of the presence of such infinite dimensions and our feelings of being isolated, lost, and completely out of touch with all other vast, unknown reaches within and outside the universe, it will help us to put parts of our known world into mutual relationships. Our soils form a very thin peel on the surface of our planet Earth. The total surface area of Earth is 510 million km^2 or 5.1×10^8 km^2. Real soils have been born on terrestrial landscapes that extend across 143,330,000 km^2 or rounded to 1.43×10^8 km^2 when we omit the area of Antarctica covered by ice during the last 2 million years. The surface area of all planets in our solar system, rounded to 1.22×10^{11} km^2, is roughly 3 orders of magnitude larger than the area of all our continents and islands, again without Antarctica. Or, in other words, the soil covering our Earth's solid surface is a thousand times smaller than the surface areas of all planets in our solar system.

The size of the surface area of all soils on our planet Earth is not a single fascinating property. There are countless processes running in that thin peel that they remind us of numerous functions running in the skin of living bodies. The comparison of soil to the skin of animals was for the first time used in 2005 by Alfred Hartemink, Secretary General of the IUSS, in the brochure prepared for the occasion of the International Year of Planet Earth. The booklet's title was *Soil – Earth's living skin.* It is stated there that without soil *the Earth's landscape would be as barren as Mars.* Awed by the parable *soil – skin*, we modified it in our book's title.

Soils evolved on Earth's continents having two specific properties, both of which are difficult to grasp and fully appreciate in terms of our everyday and lifetime experiences. One is the extremely large surface area of solid particles within the soil, e.g., if we measure it in the top 30 cm of soil below a land surface area of 1 m^2, we obtain an average value of about 10^6–10^7 m^2. It is the size of about a square kilometer or even more. The second soil property is the magnitude and importance of the hollows between the solid particles called soil pores. These pores usually occupy about 50 ± 10 % of the total soil volume and have sizes ranging between tens of nanometers up to hundreds of micrometers. The volume of millimeter-sized pores is

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usually negligibly small. The total pore space is full of life and chemical reactions and provides a variety of pathways for storage and transport within and through each soil. Muddy water is "purified" during its flow through soil. Nutrients important for the existence of plants are dissolved in soil water and enter together with water into roots. The soil pores are spaces where microbes, microscopic fungi, and all forms of life simultaneously perform various reactions and transformations inside of soil and especially in the vicinity of plants' roots. The global distribution of all soils is the essential key for water to circulate in all directions of the Earth's water cycle that we usually take for granted.

The soil could emphatically declare, "I am the protective filter and the mediator of energy, I am responsible for transformation of inorganic and organic compounds, I am the sustainer of productive life, and I am the cradle of man's life and culture. At the same time I am the medium for deposing the dust remaining after the death of man. I am the myth."

The soil could be proud that its qualities were most advanced in Egyptian mythology. The Egyptians discovered divinity in every part of environment and especially in happenings for which they had no explanation except of mythology. Just from the start of permanent settlement of the Nile valley, their experience did not predict the height that a Nile flood would reach and therefore what harvest they could expect. Low discharge meant a catastrophe especially when it happened in a series of several years and soils did not receive the needed portions of water and of fine fertile mud. But extremely high discharge resulted in catastrophe, too, with all signs of catastrophic floods. The combination of Nile discharge observation with some social acts or without current behavior of certain animals led to the birth of magic. Finally, the ritual of soil fertility amelioration was believed to be reached by repeating unusual acts or by killing animals as the bearers of oddities. The key factor of myths was the substitution of chaos by order, replacement of chaos by balance of natural forces, which were not described in an abstract form but as gods.

Ra was the great sun god at Heliopolis (Lunu in old Egyptian or On in Coptic). Shu and Tefnut were his children and Geb and Nut were their offspring. Geb was the god of earth and of soil. Osiris, the first child of Geb and Nut, was a god of nature and vegetation, and thus, he was also close to soils. He represents the Nile with its annual flooding and withdrawal; his sister goddess Isis represents the fertile farmland of Egypt, which was made productive by the Nile; one of his brothers, Set who personified evil, represents the arid desert that is separated from the Nile and the fertile land along the Nile, while his sister, goddess Nephthys, represents the marginal areas between the farmland and desert. This separation of soils was actually the first classification of soils.

Classical Greek myths speak about Demeter, the daughter of Kronos who swallowed her together with four other sisters and brothers. When she was liberated by Zeus, she was asked to take care of grain, farming, and soils. But her part among the gods started to be much more complicated. Her daughter Persephone was abducted by Hades, the son of Zeus and god of the underworld. Because she could not escape back from the underworld, her mother Demeter being extremely sad withdrew to her temple and changed the earlier fertile soils into complete infertility. The starving people stopped sacrificing to gods. With a catastrophe being imminent for mankind as well as for the world of gods, Zeus had to propose a compromise to Demeter. Persephone will spend two thirds of the year with her mother in the world and one third of the year with Hades in the underworld. Her myth explains the seasons: plants grow and bear fruit while Persephone is aboveground with her mother, but wither and die during the months she spends with Hades. Demeter instructed the first man (or Eleusinian demigod) Triptolemos how to take care of soil – how to plow, sow, and harvest. Since Triptolemos and his brother Demophon taught all people the magic of agriculture and how to keep soils fertile, they were worldwide famous by their knowledge.

In the Old Testament we find many sentences dealing with soils and their fertility. Yahweh said to his people, "Take care that the land be able to support you, when your days and your children's days are multiplied" (Deuteronomy 11: 16–21). Yahweh reminded to man that he should till it and keep it and when working he will be sweating. Hard toiling will be associated with man's cultivation of the soil (Genesis 3: 17–19). In Genesis 3: 17–19 God said to Adam: "All your life you will sweat to produce food, until your dying day. Then you will return to the ground from which you came. For you were made from dust, and to dust you will return." It shows the intimate relationship of humans and soil. In some other passages soil and water stand side by side in their importance. For example, the phrase "… like a well-watered garden…" represents fruitfulness (Isaiah 58: 11).

We find concrete instructions, e.g., in Exodus 23: 10–11a: "Plant and harvest your crops for six years, but let the land rest and lie fallow during the seventh year," or in reports about the past: Genesis 47: 23–24 reports that Joseph supplied seed for the farmers at the end of the great drought so that they could continue to farm as good years returned, or in Ezekiel 17: 5: "Then he took some of the seed of the land and planted it in good ground for growing."

Without studying historic scripts, we understand the importance of soils not only for our recent civilizations but also for all forms of life on our planet.

The soil surrounds plant roots and their growth is decisive for plants and their healthy growth is, in turn, also decisive for our life. Joan Miró, the famous Catalan Spanish surrealist and dadaist painter and sculptor, said that if we like to be real artists, we have to put down roots, which meant that an artist has to find his own style and when he succeeds, he must keep, extend, and explore it like the plant which is faithful to the fitting soil, or vice versa the soil offers the best support to the fitting plant.

Without exaggerating, we soil scientists could say that there are as many life forms in a handful of soil as there are humans on Earth. And everything – from catching the first raindrops to food production – depends on the soil. If we have studied the appropriate facts and if we now succeed in explaining them, we ought to do what is appropriate and correct with that knowledge. The jump from knowledge to actions, however, is often a huge leap – but without knowledge, it is impossible.

The study of the soil has its own scientific name *pedology* that was derived from the classical Greek words *pedon* meaning ground and *logos* meaning reason or knowledge. Its derivation had nothing to do with Latin *pes*, *pedis* (genitive case), and *pedes* (plural) meaning foot, with Greek *pais* or its shortened form *ped* meaning child, and with Greek *ped* meaning education in encyclopedia and in pedagogue meaning a child's guide. Persons studying soils are called pedologists and should not be confused with those known as pediatricians or pedophilia.

The term pedology was probably used for the first time and only once and formally in the title of the book *Pedologie oder allgemeine und besondere Bodenkunde* by F.A. Fallou and G. Wiedemann in 1862. However, the scientific approach to the principles of origin and properties of soils was still missing. We had to wait for 20 years more until the Russian V. Dokuchaev formulated the scientific principles of origin and properties of soils. His role in foundation of soil science, or pedology, has been appropriately described by A. Hartemink, who compared Dokuchaev's unique creativity to making the first Cremona violin – already perfect and ready to use since his fieldwork was accompanied by the theory and vice versa. As a result, we are all disciples of Dokuchaev.

Most people living in cities and urban communities who spend a great majority of their time in offices of institutions and in factories are used to saying "Soil is dirt." Those words are virtually never spoken by farmers nor heard from the mouths of persons living in rural areas who appreciate the local and regional essential importance of soils. We soil scientists are aware of the universal importance of soils and readily understand that without soil, life in its contemporary form would not exist today. We are organized in local clubs and national societies as well as in the International Union of Soil Science. Our cooperation in research and exchange of new theories as well as discussing the application of theories in farmers' field, the amelioration of soil properties for practical aims in water management, and the preservation of healthy soils and maintenance of profitable environments are realized at conferences and courses. The publication of papers in international journals is an inseparable part of our specialized studies. Here, we list the names of only a few of the many frequently cited journals: *Soil Science*, *La ciencia del suelo y nutrición vegetal*, *Journal of Plant Nutrition and Soil Science* (*Zeitschrift für Pflanzenernährung und Bodenkunde*), *European Journal of Soil Science*, *Catena*, *Geoderma*, *Soil Science Society of America Journal*, *Soil Technology* that was incorporated in *Soil and Tillage Research*, and many national journals of soil science, like *Canadian Journal of Soil Science* or *Japanese Journal of Soil Science and Plant Nutrition* (*Nippon dojohiryogaku zasshi*).

If we could understand the soil language, let us say Pedolang or Pedenglish, we would hear: "Hi, all of you *Homo sapiens*. Do you know me? I am the membrane on the top of Earth. I am thinner than apple peel and I have more functions than that peel. I am protecting your life, I am filtering the dissolved compounds and the finest particles from water and thus I am assuring your safe life. I am your buffer smoothing energy oscillations and balancing water excess with water shortage during droughts. I am your sustainer of life, your supporter. I have endless capacity to store useful compounds and elements and to offer pleasant environments for the genesis of new forms of life. You *Homo sapiens* should be aware of what I have just said in

Pedenglish. Therefore, today I am the soil who is supporting two soil scientists in their effort to offer you – the reader of this book – all the available information about me, the **soil**."

And we, Mirek Kutílek and Don Nielsen, shall try not to frustrate you, our soil, who has been with us continuously since we first opened our eyes.

Chapter 2
How I Earned My First Crown and Dollar

2.1 The Story of the Author Kutílek

While attending high school, I had to write an essay on fate. Now, after more than half a century, my recollection is for sure not exact, but here I at least try to keep the atmosphere:

The famous economist Antonio Usurero, who missed the Nobel Prize by just the thickness of a hair, wrote in one of his books: "…. The most important affair in our life is from how we earned the first dollar in our childhood or as teenagers. This is a sort of prediction by fairies on our future fate and destiny. It is lasting forever and it is unavoidable." Since we have been taught that the best brains of mankind are to be trusted, I am going to find out what will be my future profession.

I spent my best childhood vacations in a small Czech village *Hlinoviste* and the rough English translation will be either "Loam Site" or "Loam Pit" since loam is *hlina* in Czech. My grandma was the co-owner of a pub and of a small farm there together with my uncle, who was single at that time. During harvest my grandma and uncle were obliged to be in the field, but they had to keep the pub open for the old men of the village who were no longer farming, but nevertheless typical of how all farmers used to be – thirsty not only in the evenings but throughout the entire day. After I was given the keys of the pub and its cellar, my duty was to tap beer and cash the guests if they were leaving. Being a student in fourth grade and excellent at adding, subtracting, and simple arithmetic, I had no problems cashing the guests. If they paid by notes, it was an easy task for me to give their change back in smaller notes and coins.

When my grandma came back from the field, she found some of old guests still in the pub.

With his index finger pointing at me, one of the group of old men at the table reserved for regular guests said, "You have a perfect headwaiter!"

"Do you think so?," asked my grandma with pride being felt in her voice.

"How old is he?," asked the curious old man.

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"About five," answered my grandma, whose memory was chaotic when discussions were about age. Actually, she stopped counting my years when I was 5 years old.

"He is a genius," exclaimed the thin old man, and all guests repeated in chorus: "Genius!" From this moment on I was the little genius for all guests from our village Loam Pit. When their bill was about three crowns and several hellers, they paid five crowns and they left me more than one crown tip and I was the best tipped waiter in the county side.

My fate is to be the headwaiter, I wrote at the end of the essay.

Our high school teacher was beautiful with a perfect makeup. All of my friends fell in love with her and the more we recognized our hopelessness, the cheekier we were. She asked me: "Where did you read about the economist Usurero? Never heard about him."

"He is well known among professionals in theory of economy," I was lying. I would never admit that I derived this imaginary name from the Middle English word *usurer* that means a lender of money at huge, unlawfully high interest rates. Knowing that the Latin *usura* means loan, I invented the Italian family name of Usurero by adding an "o" to the end of usurer. I also remembered from history that after Italians started banking, the somewhat dirty term bankruptcy stemming from Italian *banco rotto* meaning broken bench became a common word. In those times, bankers illustrated their ability and readiness for making loans by sitting on a box-banco containing available cash. They rotated the big box up and down to demonstrate the sad situation whenever cash was no longer available for more loans. While I was writing my essay at the high school, I decided to improvise the name of the economist as well as his well-known professional recognition.

I was pleased when she responded, "Strange name. But you wrote the essay well."

After that, everybody at school started to call me *pingl*, a Czech vulgar expression for a trainee waiter.

It took me more than 10 years to recognize that my nonrealistic quotation of an imaginary Usurero was correct but in a different way than deriving my fate from my pub expertise. My imaginary Usurero predicted correctly that my lifetime fate would be related to the name of the village where my granny owned the pub. With that name being Loam Pit, my fate was not only linked up with loam but with all soils. Although I started my university study in civil engineering, division of water management, after I recognized what an important role soil plays in the hydrologic circle, I decided to shift my studies into the direction of soil hydrology and soil physics. It happened during the period when many basic equations of water flow in soils were formulated, and on many occasions, I felt like I was living in a scientific thriller as I watched all sorts of mathematical magic being performed by my slightly older colleagues. Because I wished to be a similar magician, soils and water together with their governing physical laws attracted my attention for the rest of my life. This is also why I decided to share my experience with lay readers in telling them about the really magical role of soil in all life forms on our planet Earth. My longtime and best friend Don Nielsen is not only accompanying me, he has often a leading role.

2.2 The Story of the Author Nielsen

During and following the Great Depression (1929–1939), I spent my early youth living in the developing town of Phoenix located within the arid, dusty region of Arizona in Maricopa County across which the dry bed of the Salt River has been existing for centuries. Today, my memoirs actually agree with the statement, “The most important affair in our life is from how we earned the first dollar in our childhood or as teenagers,” creatively derived by Kutílek who invented and fictitiously quoted a famous economist named Antonio Usurero.

While behaving and minding my parents and doing a few designated chores in and around our 2-bedroom wooden home, I never thought of working for money because my whims for occasional extra enjoyment were always bought with a few cents given to me by my parents. Some of my friends having rich parents were given weekly allowances to buy ice cream, candy, and junk. But without spending a penny, I enjoyed walking through uninhabited desert regions observing plant and animal life together and also picking up archeological artifacts from Hohokam Indians that I always found on different kinds of soil surfaces. During any of my treks, I often saw javelina, burros, coyotes, wolves, turkeys, buzzards, as well as smaller creatures such as turtles, lizards, rattlesnakes, horned toads, scorpions, tarantulas, ants, spiders, centipedes and millipedes, crickets, earthworms, etc. Having also frequently found archeological artifacts on and below soil surfaces, I saved arrowheads made of flint, stones shaped and used as tomahawks, various grinding stones and bone awls, pieces of turquoise jewelry, ceramic and adobe figurines, and fragments of decorated pottery.

As the depression gradually ended, my desire steadily expanded to enjoy costly activities. Without wanting to further empty the pockets of my parents, I sought any kind of a job to earn some money. Luckily, a part-time job suddenly appeared that I could do each day after school and on weekends. Surprisingly, the surroundings of my first paying job were similar to those encountered on my treks walking on dry soil through the dusty desert environment. Working indoors in a retail store filled with books, baggage, and suitcases that were continually being covered by dust blown into the store from unpaved streets and fallow soils in the sunbaked vicinity, I earned my first dollar repeating what I had already done for years outdoors in the desert. In both cases, I sorted, picked up, individually dusted off, and rearranged each of the objects. In the desert, they were living organisms or artifacts at or near the soil surface. In the store, they were books and baggage that I nicely rearranged after dusting each of them and also after removing lice and silverfish potentially harmful to the books as well as killing unwanted insects, spiders, and rodents.

My first full-time job also involved dusty conditions – digging and sampling soils across farmers’ fields to ascertain deficient levels of plant nutrients and also searching for unwanted pests that reduce crop yields. By the time I was about to finish high school, I was happy breathing dusty air while digging in dirt working with farmers. After telling my father, who was a farmer during his entire life, that I had decided to study agriculture in college, he gasped and emphatically said, "Never! Do you really wish to follow my footsteps working every day from sunrise to long after it's dark without ever having time or making enough money to take a decent vacation? I strongly advise you to study accounting, economics, or some topic to make money. Do not study agriculture and become a farmer like me."

Two months later and convinced that I should strive to become a wealthy accountant or business manager, I entered college. During the first term I took these courses: accounting, economics, business mathematics, sociology, and history. By the middle of the term, I knew that I made a mistake even though I made excellent final grades in all five courses. By the following term, switching gears from money to science, I took botany, chemistry, entomology, geography, and geology. And 3 years later at a different university, I graduated with a BS degree in Agricultural Chemistry and Soils. But with that knowledge and experience gained in classrooms and laboratories and across various landscapes, the exact meaning, behavior, and importance of dust remained somewhat of a mystery to me in relation to the plant and animal life that I had observed in the desert as a youngster. Being curious, I continued my science-related education by exploring the impact of dust and soil particles on microbial communities living within desert topsoils. My exploration was enhanced by using newly available radioactive elements to determine critical levels of carbon, nitrogen, and phosphorus being manipulated by millions of soil microorganisms living in the vicinity of each and every root of a plant. Their dominance controlled the fate of each plant – its metabolism, growth, survival, and reproduction – as well as communities of plant species that thrived or were exterminated on each soil across the desert. Earning an MS degree in soil microbiology was exciting – it opened my eyes and improved my understanding of what I could not see as a teenager without a powerful microscope.

My curiosity continued regarding my early observations of various kinds of animal communities thriving in dust-laden arid regions without any obvious sources of readily available water. With the bulk of each of their individual bodies being composed of water that tends to evaporate daily, where did they find water in desert regions with rain limited to 1 cm per month? Such rainfall seldom provided enough water to accumulate in creek beds that remained dry throughout the year. Not understanding how water infiltrated into and migrated through desert soils nor how communities of micro- and macro-sized animals meandered through and between local hydrological regions of arid to humid environments, I switched my attention to the impact of soils and water on the diversity of animal life by studying soil physics – a combination of soil hydrology, mathematics, and physics conceptually integrated with the sun's energy at the soil surface. Four years later, I earned the PhD in soil physics after analyzing infiltration and redistribution of water within five different field soils using the first homemade portable neutron soil water content measuring device; I continued my childhood habit of walking across the landscape and collecting historical artifacts from the soil. At that time, being nearly 30, married and a father, I was well on my way to fulfill the fictitious quote of Antonio Usurero.

Having lived in only two regions, the desert floor of Arizona and the corn belt of the USA, during the next 20 years I learned more about life on Earth by walking across and digging holes in soils developed under different climates on all continents except Antarctica. Although each trip offered an opportunity to learn something new, every trip ended with my books, baggage, and suitcases needing a thorough dusting just as if I were still earning my first dollar in the bookstore.

Only halfway through my career and still learning, my academic life received a once-in-a-lifetime boost as a result of meeting Kutílek during an international scientific meeting. Although he may assert that when we met he belonged to a country in the underdeveloped part of the world of sciences, he was at that time and remains today a contemporary leader for explaining the evolution of plants and animals including *Homo sapiens* and their adaptability to the ever-changing conditions of soils and global climate. Before meeting him, it never occurred to me to seriously include long-term geologic processes associated with soil genesis, paleopedology, climate change, and archeology that had impacted contemporary soils and their living communities. And as I walked across and dug into dusty soil surfaces around the globe, I never thought of myself as being a member of the living community that I sought to understand.

The second half of my career, filled with many visits to outdoor environments examining soil profiles, fossils from the past, and artifacts stemming from prehistoric communities, was absolutely exquisite owing to my unique inspiration from frequent communications with my greatest personal friend, Kutílek. I even returned to Arizona to walk once again down to the bottom of the Grand Canyon, but at that time, to observe different geologically buried soil profiles, to study remnants of deteriorated Native American villages, and to pay more attention to the impact of the Colorado River eroding and cutting through a region that began to uplift 75 million years ago. And of course, each visit ended with the necessity of removing the dust that accumulated on my baggage and me.

As I recall my lifetime activities, I now believe that the statement attributed to Antonio Usurero by Kutílek was absolutely true – not fictitious. I was born in a dusty environment; earned my first dollar in the middle of a dusty room; spent my entire career studying the intricate complexities, movements, and reactions of dust in living and inert entities on the Earth's surface; and today still learn more about soil without focusing on activities to become rich or to make lots of money. I have always and happily followed an exploratory path directed into soils. I have no intentions to stop in the future until, like other living global organisms, my lifeless residues rejoice within the soil and other domains of the Earth's captivating environment.

Chapter 3
Soil Is the Skin of the Planet Earth

We have mentioned earlier in the introductory chapter that recent soil scientists like to say in their scientific jargon that the soil is a sort of skin to our planet Earth. When we have now more space and the reader has more time, we can afford the luxury of going into some details. First, this comparison is not exact because we mammals are born with skin, have it at the beginning of our existence, and continue to have skin throughout our lives even if it is not in perfect condition upon death. Hearing the parable about Earth's skin, others may deduce that soil and the Earth were created simultaneously. Such a conclusion is not valid. The soil, or the Earth's skin as we used to say, started its existence when macroscopic life was moving from oceans to the mainland, to the surface of continents and islands. This migration was happening roughly 500 million years ago – maybe even a little bit earlier. It was the time of Earth's adolescence and certainly not immediately after the birth of our planet. During this period, various kinds of proto-soils gradually began to uniquely develop and slowly appear at diverse locations. Before this time, only weathering fragments and remnants from rocks – stones, gravels, sands, and even clays – scattered across continental surfaces, completely void of any action by living macroorganisms. Without the contributing actions of these organisms, a soil cannot exist. Although some microorganisms, mainly bacteria, were thriving at that time, their contribution to the transformation of the weathered inorganic rocky material was negligible and has not been documented. As our initially skinless planet aged, an outer jacket of soil eventually became a reality owing to the essential actions of macroscopic life. Real soil does not exist without such a living community.

Another snag or incongruity can be identified in the everyday analogy that compares the relative thickness of the soil on the Earth to that of the skin of humans or animals. The soil layer forming the boundary between the Earth and the atmosphere has a thickness usually of only 1 m, sometimes 2 m, and rarely more than 2 m. This layer in the context of the Earth's radius of 6,378 km is extremely thin – it is about six million times smaller than the radius of the Earth. Sometimes the soil layer is about three million times smaller than the radius of the Earth. Generally, we can say

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that the soil's thickness is about million times smaller or six orders of magnitude less (10^{-6}) than the radius of Earth.

On the other hand, the thickness of a human's skin is a thousand times smaller than a human's height, or it is by three orders of magnitude smaller (10^{-3}). The relative thickness of the protective layer of the Earth is a thousand times less than that of humans. In order of magnitude it is 10^{-3}. Comparing the relative thickness of a human's skin to that of the soil, humans are protected much better by their skin than the Earth is protected by its thin soil layer. When we consider a broad number of continental mammals of all sizes, we learn that the relative thickness of their skin is somewhat smaller than the human skin but never falls below a relative magnitude of 100. With the relative soil thickness of Earth being substantially smaller than the relative skin thicknesses of both humans and mammals, we expect that the soil protects the Earth less than the skin protects either humans or mammals. We must take into consideration this expectation of vulnerability when we start discussing the birth, longevity, and death of soils and realize that even a very thin soil is still an unconditional requirement for life on Earth. Regardless of the thickness and continuity of the Earth's topsoil, many geographic locations are not acceptable or conducive for human life owing to local environmental conditions causing extremely thinned or even destroyed skin. We should always remember that the skin of a mammal is protecting just that particular species, while the skin of the Earth is ensuring all forms of life on all continents of our planet.

Our opponents who may not consider the necessity of the myriad of biological processes contributing to the health and safety of the Earth's skin could raise objections against our relative thickness estimates of soils. Merely focusing on physical processes occurring within the transition from the Earth's rocks to the atmosphere above its surface, they may well limit their thoughts to transport between solid and gaseous states in the absence of biological processes. If we accept their statement that the rough average thickness of the Earth's solid crust is about kilometers, we calculate that the actual measured soil thickness of 1 m is more than hundred thousand times smaller than the solid Earth's crust (i.e., in order of magnitude 10^{-5}). Compared to human's skin thickness, it is hundred times less. Considering the mammals' skin, the soil is between ten times and hundred times less than the mammals' skin.

Let us first simply assume that there is a linear indirect relationship between the thickness of the skin and its vulnerability. Then the extremely fine thickness of the Earth's skin – the soil – would mean that the most important Earth's property would be very imperiled if the soil characteristics strongly and abruptly changed. It remains now to show what we consider is the most important property of the Earth. Being egoistic members of a biological order and desiring the sustainability and continued development of positive life conditions for ourselves, we designate the most important property on the prerequisite that it is subject to evolutionary principles. Any abrupt change in the characteristics of the Earth's skin should therefore be avoided. Accepting this principle, soil has a decisive, ever-present influence upon all forms of life activity on Earth. It is a diverse global system of sustainable yet ever-changing local and regional environments that support and delineate micro- and macroorganisms within and across all landscapes. For each location, soil facilitates roots from a plant or a canopy of plants to be anchored in a specific location to thrive and reproduce. Soil together with its vegetative cover keeps the contemporary gas composition of the atmosphere relatively constant – a stable condition required for the existence and survival of human life. Soil retains water from irregular rainfall and irrigation events and offers it with dissolved essential nutrients to plants through their roots in a remarkable, unswerving manner. Soil is the home of countless microorganisms that cause the decomposition and transformation of decayed organic bodies with some of them contributing to the fixation of atmospheric nitrogen. Other microbial species cooperate with roots to such an extent that we could say that they are grazing on the roots causing at the same time a profit for the plant. This type of symbiosis helps both sides – the plant and the microbes. In addition to the activity of microorganisms, we find that soil is the home of ants, termites, earthworms, and huge numbers of related macrofauna that all contribute directly or indirectly to the global vegetative community. Plants could not exist without this continuing chain of influence. The life of herbivores is impossible without plants and the same is valid for us, even if we succeeded in transforming mankind from omnivores to herbivores. And we are not speaking about the majority of us who reject the idea of only veggies.

The modern vocabulary of ecologists permanently retains the term biodiversity. It means the degree of variation of life at all biological levels starting from cellular level up to plants and animals. Biodiversity depends upon the favorable conditions for existence and for evolution of all forms of life. It is our pleasant duty to mention that the biodiversity in soil is much greater inside of the soil than above the soil surface among plants and all animals. Those among the ecologists who are so conscientiously worried about biodiversity should be careful about soil in a same way or even more as they are about living organisms. Why? Because if the biodiversity of soil were lost, an immediate loss of biodiversity on the entire planet Earth would follow. We expect ecologists to preferentially protect soils from their misuse and from the potential, eventual destruction of soils' ability to support life on Earth.

However, many commonly accepted practices of managing soils are destructive even though laymen do not recognize them. A typical example is the planting and cultivation of monocultures that allows a single crop or plant to be grown in a farmer's field or similar areas for a large number of consecutive years. Such a practice steadily leads to the exhaustion of a certain nutrient or group of nutrients which become the most important factor for plant growth with harvests becoming more and more reduced year after year. Even when the availability of the essential nutrient is increased by an annual supply of mineral fertilization, one or more other required nutrients or substances start to diminish or virtually disappear. Eventually with continued monoculture, this lack of irreplaceable matter causes a weakening of the root system, a reduction of growth of the aboveground plant parts, and a deterioration of the effectiveness of the physical, chemical, and biological properties of the soil. However, this result is only one part of the ugly face of monocultures.

Repetitiously cultivating the same crop on the same field also enhances the development of weeds and plant diseases because the natural processes of plant protection are gradually reduced until they approach zero. To combat these unwanted developments and intrusions, farmers apply various kinds and combinations of herbicides and pesticides with some timely short-lasting success whenever they obtain a reasonable harvest. However, even with highest selective agrochemicals yet to be produced, their application in scientifically recommended amounts impacts and even kills countless numbers and kinds of beneficial soil micro- and macrofauna and soil micro- and macroflora – all of which were not the weeds and plant diseases targeted by the farmer. In simple terms, monoculture paves the way for soils to become sick and stripped of their biodiversity.

We will show later on how this plundering of soils leads to the deterioration of all features of the landscape. The negative consequences are not just linked to local catastrophes occurring in the past. We find even today a small-minded approach to grow plants solely for their organic content in order to produce biofuels. They are frequently grown for many years in the same field on an originally very productive soil. Such monoculture fields initially produce abundant yields that are easily harvested and immediately sold for high profits. By continuing such monoculture, we are repeating the same error of our grandfathers, who on so many farms transformed a very fertile soil to a nearly unproductive soil. The recent approach producing a large portion of the biofuels now available is an example of fighting fire with fire. Although we are trying to be less dependent on fossil fuels by producing biofuels, we are forgetting, or perhaps we do not even realize, that we have an undesirable by-product. That by-product is soil having a substantially reduced biodiversity that is not immediately recognized nor considered as important as when a particular species of mammals disappears. The picture and story of the poor animal is published all over the world, while soil plundering is only mentioned in scientific and professional journals. Who among the countless nonprofessionals throughout the world has ever seen any photography of perished soil microbes or fungi? Without speaking about a complete movie, there has never been even a single photo transmitted to any household television set about the disappearance of a microbial colony. It could be that those exact microorganisms in the disappearing colony had been protecting plant roots from attacks by pathogens. Or within the disappearing colony, at least some groups of microorganisms were guaranteeing the beneficial disintegration of decayed plants and animals and the transformation of decomposition products into new organic complexes important for the quality of soils. If those groups disappear, the quality of soil drops sharply. Therefore, it is the biodiversity of soil organisms that is important for soil survival and thus for human civilization.

Christian religions have accentuated the importance of soil by both word and parable. Mankind started with Adam in the Old Testament. It is the word derived probably from the Hebrew *adamah*, a feminine word denoting the earth. Another word *ahava* meaning love is similar to the name *Eva* that means life and it is close to *hayya* that means alive. By combining *Adam* and *Eva* we obtain the living earth full of love. To avoid just a celebration of soil at the start of mankind, we have to mention that *to ´evah* also means abomination. But it may also mean dirtiness, and if it does, we are back to our soil. Generally, there are several other related meanings coexisting like melodies in the sound from an orchestra.

Soils are not everywhere the same. They change remarkably even along small distances, and when climatic and vegetation conditions change substantially across large distances, their physical, chemical, and biological properties differ to such an extent that their similarity is absent, and soils even display huge assortments of different colors across local, regional, and continental landscapes. Variations of soil are neither chaotic nor by haphazard and correspond to strong relationships imposed by spatial and temporal environmental conditions according to scientific laws. Soils in tundra regions differ substantially from soils of steppes or prairie lands, and they again diverge from soils in humid tropics. Even a nonspecialist recognizes differences according to the color of the soil in a trench or an excavation for a road. A layman notices that tropical soils are usually not gray or grayish brown but much more colorful and sometimes reflect colors of the entire spectrum of a rainbow. Soils differ substantially not only within great distances of climatic and vegetative zones but also within much smaller distances. For example, soils vary along the slope as well as within the valley at the bottom of the slope. Soils are taxonomically classified into orders, suborders, great groups, subgroups, families, and series in a similar way as are other natural resources are classified. Taxonomical systems are not yet globally unified. This is not the only scientific disadvantage, but it is a practical drawback. We have to consider the fact that soils with their crop and animal productivity are an important basis of the non-predictable daily changing market values of national economic resources.

Soils are as vulnerable as living organisms. As the environmental system changed during the geological evolution of our planet and beginning at the time when living organisms occupied the land, soils developed and changed continually. We can find sometimes the remnants of those past soils. They are called paleosols and we devote more attention to them later on in Sect. 13.3, Granny Soils. These earlier existing soils are sometimes buried under the dust and ash of the past volcano eruption, or they are hidden under thick layers of loess blown by windstorms occurring in the very cool climate of glacials during the last two million years of Pleistocene. Similar to a snowdrift, a loessdrift could form to a depth of several meters, but the time for its development differed greatly from that of snow. Without interruption, loessdrifts were formed during tens of thousands of years. In this way the paleosol, being older and lying under the loess, was preserved. In some instances, paleosols are found hidden below the sediments of rivers.

Abrupt changes of the global environmental system have been caused by the catastrophic impacts of asteroids or a comet colliding with the Earth. Soils were completely destroyed – only small remnants have been found under layers of fossil dust and ash. When such catastrophes happened, soil disappeared from the entire continents. And after such events, because the climate and vegetation changed, the new slowly formed soils differed from the earlier soils. Without the impact of an asteroid, serious soil damage in the last 11,700 years during the Holocene has been caused by human activity. This damaging activity, strengthened during the previous two centuries, has recently led to catastrophic consequences in some regions.

In one of civilization's cradles, Mesopotamia, some dynasties collapsed after introducing a primitive irrigation system that accelerated rather than restricted soil salinization processes typical for the arid region. Crop yields dropped so much that the governing centers were obliged to abandon regions where initially fertile soils gradually became infertile and unproductive. The king and his administration had to initiate a new administrative center in another area of soils with no or little salinity. The new region appeared promising to feed the population.

Great damages are caused by soil erosion by the surface water flow, especially when the physical quality of the soil on the surface is strongly reduced. Water flowing on the slope of bad-quality soil transports soil particles so intensively that the most fertile soil layer, the surface horizon, is smashed. With all of the soil particles being carried away and gullies formed and subsequently washed out, the soil is finally destroyed.

Another example of soil destruction often occurs when the same crop, e.g., wheat or cotton, is grown year after year on the same field. This practice of monoculture, already mentioned above relative to plant nutrient availability and soil biodiversity, also causes deterioration of the strength and stability of the topsoil. Beneficial small lumps of soil known as aggregates disintegrate into separated sand, silt, and clay particles that are detached from the soil surface and carried away by wind forming dust storms. As the wind subsides and particles settle down, their hot dust scorches and destroys crop plants in the wind-eroded field as well as those in nearby fields.

The destruction of agricultural landscapes by severe dust storms during previous centuries is well documented by scientific evidence. The dust storms remembered most frequently are those that destroyed large regions in Ukraine of czarist Russia in the past. Catastrophic droughts accompanying the dust storms were described also in the classical Russian literature of the nineteenth century. Similar dust storms and droughts impoverished tens of thousands of American farmers in the 1930s of the twentieth century. The destructive erosion process, either by wind or by water, or by combination of both may reach so far that all soil is carried away leaving only a completely unfertile sublayer and rough rock.

Soil has a miraculous ability to accept many strange materials and to transform them into an integrated part of its existence. However, if people do not consider the limits of those capabilities and overload a soil with mineral or organic wastes, the beneficial transformation of such wastes into a soil process is no longer a possibility. With such human negligence, those wastes buried in soil eventually become unwanted toxic products that gradually overwhelm the soil into a medium that does not support plant communities.

Modern contemporary society has a new perfect tool for the complete destruction of soils: constructions. We are not speaking about construction of new houses and dwellings for still increasing numbers of population. We are speaking about one- or two-storied shopping centers, warehouses and administration buildings, roads, and airports. They occupy hundreds of thousands of square kilometers where the soil was dug out and replaced by concrete, pavement, and asphalt. With the new surfaces being impermeable and not allowing a drop of rainwater to penetrate into and down through the remaining subsoil, hydrologic cycles are destroyed. Without soil, the natural liquidators of wastes, soil microorganisms, do not grow on these constructed areas and, hence, drastically redistribute the location at which dead