SOIL ATLAS OF EUROPE

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

ies
Institute for Environment and Sustainability

European Soils Bureau Network

PUBLISHING DETAILS

The citation for this document is:
Soil Atlas of Europe, European Soil Bureau Network
European Commission, 2005, 128 pp
Office for Official Publications of the European Communities,
L-2995 Luxembourg

Catalogue Number LB-37-01-744-EN-C
ISBN 92-894-8120-X
EUR 21676 EN

Printed in Belgium and Italy.

Cartographic Representations
Cartographic features depicted on the maps of this atlas are derived from the EUROSTAT GISCO database *(Geographic Information System for the European Commission, EUROSTAT, Luxembourg)* and from the Digital Chart of the World. These cartographic data do not have an explicit legal status; hence, no legal aspects should be derived from the information depicted on any of the maps in this publication.

Cover: The different colours on the map correspond to the distribution of the major soil reference groups across the European continent (JRC).

Soil Data: European Soil Bureau Network. For additional information, please contact the Soil and Waste Unit, Institute for Environment and Sustainability, European Commission DG Joint Research Centre, Via Fermi, 21020 Ispra (VA), Italy.

Maps produced by the Soil and Waste Unit, Institute for Environment and Sustainability, DG Joint Research Centre, Ispra.

Final design and graphical support by Lovell Johns Limited, 10 Hanborough Buisiness Park, Long Hanborough, Witney, Oxfordshire, OX29 8RU, United Kingdom.

The guiding principle of this book was that soil should be made as simple as possible, but no simpler (based on a quotation by Albert Einstein).

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Acknowledgements

This atlas is the result of more than ten years of fruitful effort and collaboration between the European Commission's Joint Research Centre in Ispra, Italy, and Europe's leading soil science institutions. Without this considerable cooperation, the production of this atlas would not have been possible. The authors gratefully acknowledge the assistance of following individuals and organisations. We also offer our apologies and thanks if we have inadvertently and unintentionally omitted anybody.

For his constant support to the project, special thanks are due to Giovanni Bidoglio, Head of the Soil and Waste Unit, Institute for Environment and Sustainability, Joint Research Centre, Ispra, Italy.

For their considerable and invaluable advice and contributions during the drafting of the atlas, the authors appreciate the efforts of Peter Bullock, Henrik Breuning-Madsen, Raoul Dudal, Wolf Eckelmann, John Hollis, Selim Kapur, Mark Kibblewhite, Erika Micheli, Juan José Ibáñez Martí, Freddy Nachtergaele, Vladimir Stolbovoi, Jan J.H. Van Den Akker, György Várallyay and Pandi Zdruli. Without their contribution, this publication would be significantly poorer.

For their guidance, direction and support to the project, the authors thank the **Editorial Board of the Soil Atlas of Europe.** These include:
Arnold Arnoldussen, Stanislaw Bialousz, Pavol Bielek, Winfried Blum, Jaume Boixadera, Henrik Breuning-Madsen, Vanda Valerija Buivydaite, Raoul Dudal, Wolf Eckelmann, Alexandra Freudenschuß, John Hollis, Selim Kapur, Aldis Karklins, Nikola Kolev, Josef Kozak, Mark Kibblewhite, Christine Le Bas, Franc Lobnik, Donatello Magaldi, Erika Micheli, Juan José Ibáñez Martí, Freddy Nachtergaele, Loit Reintam, Vladimir Stolbovoi, Jan J.H. Van Den Akker, Eric Van Ranst, György Várallyay, Sonya Sammut and Pandi Zdruli.

In addition, the maps at the core of the atlas are based on the efforts of the scientific contributors to the Soil Map of the European Communities 1:1,000,000 (CEC, 1985)
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The scientific contributors to the compilation of the European Soil Database.
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Finally, the authors are grateful for the flexibility, understanding and professionalism of Peter Markley, Christine Bond, Clare Brown, Ian Dewsbery and Richard Hewish at Lovell Johns Ltd throughout the, sometimes tortuous, process of assembling this publication.

Picture Credits

The authors would like to thank the providers of graphical elements (photographs, diagrams, illustrative maps) for their permission to use their material in the atlas. All contributors are listed below:
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CONTENTS

An example of a dolina from Croatia. This feature occurs in regions where limestone has been dissolved by rainwater to create a landscape known as karst (virtually no rivers or streams, many depressions, fissures and collapsed structures). Soil accumulates in these depressions and provides a stable, nutrient rich natural unit for cultivating crops (EM).

Soils can preserve information about the environment in which they were formed. The photograph above shows the Artrkar soil in Hungary, a unique formation resulting from the changing environment since the end of the last ice age. The striking patterns are caused by freezing and thawing soon after the last ice age some 10,000 years ago and have no relation to the present day climate (EM).

PREFACE

The European Union has established within its Sixth Environmental Action Programme the need to prevent soil degradation in Europe. In order to achieve this objective, the EU proposed to develop a specific thematic strategy for soil protection. The way forward towards such a new strategy has been presented in a Communication from the Commission entitled "Towards an EU Thematic Strategy for Soil Protection"[1]. where a number of major threats, i.e. erosion, contamination, decline of organic matter content, loss of biodiversity, sealing, salinization, landslides and flooding have been identified.

Some features of soil, such as its enormous variability or the fact that soil is mainly privately owned in Europe make the development of a soil protection policy somewhat different from the protection policy of air and water. Soil diversity reflects differences in climate, geological origin, vegetation, land use and historical development that are the main characteristics of European landscapes. Recognizing soil diversity implies taking into account the strong local component of any soil protection policy. Different soil types require different management and protection measures.

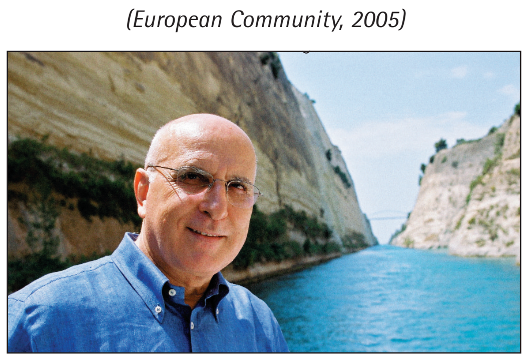
This new "Soil Atlas of Europe" is intended to be a step towards raising public awareness on the importance and the key role of soil for many human activities and for the survival of ecosystems. The Atlas compiles existing information on different soil types in easily understandable maps covering the entire European Union and bordering countries. The publication is intended not only for the specialized reader but also for the general public, aiming to 'bridge the gap' between soil science, policymaking and public knowledge. By addressing a non-specialized audience, the Atlas will increase public awareness and understanding of the diversity of soils and of the need to protect this precious resource.

Recognizing the importance of soil as a non-renewable resource which provides many functions crucial to human activities as well as ecological functions (hosting soil biodiversity, the filtering and buffering capacity, the role as an archive of cultural heritage, etc.), will support the development of protective measures that will incorporate local knowledge about each specific soil type and function as well as safeguarding soils for future generations.

The Atlas draws on the expertise and activities of the Joint Research Centre in this field and has been elaborated in close collaboration with specialized institutions in Member States and bordering countries participating in the European Soil Bureau Network.

We trust that this publication will be a major step towards a better understanding of the soils of Europe and their diversity , thus fostering and strengthening the commitment of the European Union to protect and preserve our soil.

Janez Potocnik
Commissioner for Science and Research
(European Community, 2005)



Stavros Dimas
Commissioner for Environment
(European Community, 2005)

[1]. COM 179 (2002) see http://www.europa.eu.int/comm/environment/soil/index.htm

FOREWORD

Soil is a finite resource that is under pressure from many activities, mostly human induced. It is clear that the European Commission must be at the forefront of developing policies and effective practices to protect soils across Europe. It is in this context that the Directorate General Joint Research Centre (JRC), as the European Commission's research centre, is carrying out research and collecting information with the aim of better understanding the processes that lead to soil degradation, investigating possible remediation techniques and evaluating the effect of policy changes on soil resources.

As many of the issues affecting soil cross national boundaries or administrative areas, responsibility for soil protection is not always easily defined. To address this issue, the JRC is already working towards the goals outlined under the European Research Area initiative by actively co-operating with key players such as the European Soil Bureau (ESB) Network. The JRC's Institute for Environment and Sustainability hosts the Secretariat of the ESB and brings together, on a regular basis, expert scientists in the field of soil science. This network provides harmonized and coherent information on European soil to policy-makers and other users. Established more than 10 years ago as one of the major scientific reference networks of the JRC, it has been expanding over the past years to cover more than 40 countries and will continue its activities also in the future supporting the new EU Thematic Strategy for Soil Protection.

I am pleased to see that the result of the collaboration between the JRC and the ESB Network has resulted in this striking, informative and timely document. This Atlas not only marks the advent of Soil Protection legislation but also coincides with the Enlargement of the European Union – both areas where the JRC has been very active in supporting the development of European policies

I hope that you will find this Atlas both enlightening and motivating.

Dr. Roland Schenkel
Acting Director-General of the JRC
(European Community, 2005)

INTRODUCTION FROM CHAIR OF EUROPEAN SOIL BUREAU NETWORK

European soil is an immensely valuable World resource, which requires protection to ensure future global food security and environmental quality. Soil forms over very long periods of time and once destroyed it is effectively lost to present and future generations. Europe is blessed with highly productive agricultural soil, but the continent also has vast natural and semi-natural lands, in which soil plays a vital role by conserving biodiversity and supporting global environmental systems. Thus soil is a living system that is a type of natural capital available to enrich the lives of citizens.

The 'Soil Atlas of Europe' is important because of the growing threat to soil resources and the need to raise awareness of their value to society. The Atlas illustrates vividly the great diversity of European soil and it is intended to both encourage and underpin the development of new policy measures for soil protection. Compilation of the Soil Atlas has been made possible through the mature and deep collaboration existing within the European Soil Bureau Network (ESBN), which joins centres of excellence throughout continental Europe specialising in the survey, analysis and monitoring of soils. The Network's origins go back more than 50 years, when the idea to construct a soil map of Europe was first proposed. In its current form, it has been an operational network of the European Commission for more than 20 years. The ESBN includes soil institutions from all the Member and Candidate States of the European Union, as well as some Neighbouring Countries to the east and south, and it works closely with the Services of the European Commission, the European Environment Agency (EEA) and international institutions such as The Food and Agriculture Organisation (FAO) of the United Nations. It is a successful European collaboration that has a critical role to play over the coming decades.

Accelerating global change is bringing new challenges to soil management. More intensive land use and the extension of urban areas place new pressures on soil resources. Yet there is little account being taken of soil properties in spatial planning and there is widespread damage to soils caused by erosion, contamination and other threats, such as declining organic matter and biodiversity, compaction, sealing and salinisation. Looking ahead, adapting to climate change will require more information about soil resources and their response to altered weather patterns, so that future capacity to support food production, environmental services and biodiversity can be assessed. In short, there is an urgent need for better soil protection to secure irreplaceable soil-based services. In recognition of these requirements and under the EU Thematic Strategy for Soil Protection, the European Commission is providing essential leadership. The ESBN stands ready to continue its supporting role as a pan-European source of high quality soil information and technical advice.

It is hoped that the Soil Atlas of Europe will encourage a greater interest and appreciation of European soil resources and of their importance to economic, social and environmental well-being.

Mark Kibblewhite

Professor Mark Kibblewhite
Chairman, Steering Committee,
European Soil Bureau Network
(NSRI, 2005)

Introduction

Cultivated soil allows the production of crops that are essential for human existence (EM).

Soil can vary enormously. Soil characteristics can change across the landscape and also with depth. The soil under your feet will be quite different from that just 40cm deeper. The above picture shows the vertical changes in a soil profile that has developed on the flood plain of a river valley. The dark band below the surface is rich in organic matter while the pale zone below is due to the accumulation of lime (calcium carbonate) by water percolating through the soil. Note the presence of gravels deposited by the river at the base of the profile (EM).

Scope of the Atlas

Soil is one of the fundamental components for supporting life on the planet.

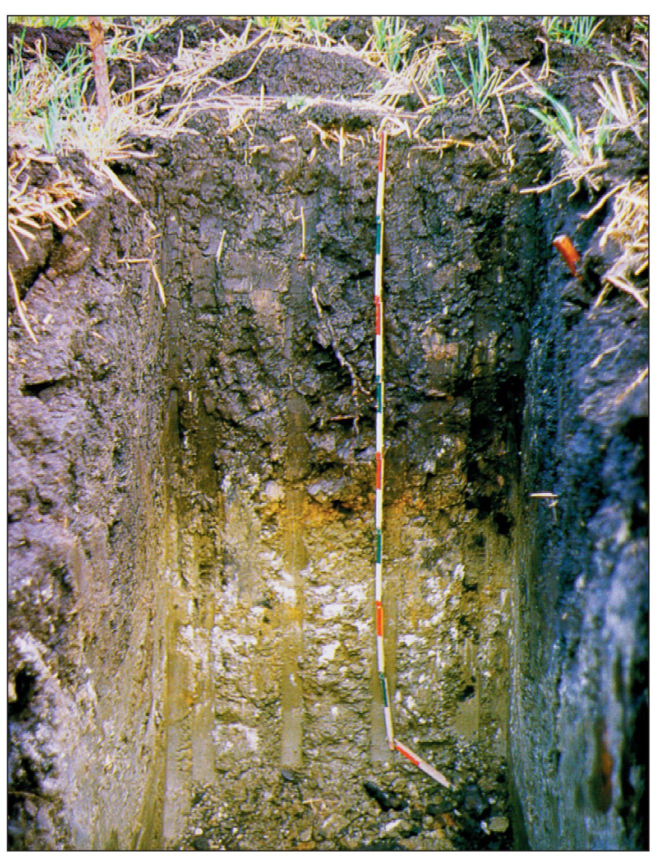
Soil can be defined as a mixture of rock particles, organic matter, air and water that occupies the uppermost few metres of the Earth's crust.

Soil performs a number of key environmental, social and economic functions that are vital for life. Plants and crops are dependent on soil for the supply of water, nutrients and as a medium for growing. Soil stores, filters, buffers and transforms substances that are introduced into the environment. This capability is crucial in producing and protecting water supplies and for regulating greenhouse gases. Soil is a provider of raw materials. Soil is also an incredible habitat and gene pool – in excess of 5 tonnes of live organisms can exist in a hectare of arable soil. Soil is a fundamental component of our landscape and cultural heritage.

Simply put, without soil, the Earth and society as we know it, would not function. It is no coincidence that the word *earth* is used for both soil and the planet that we live on.

In order to perform its many functions, soil condition must be maintained. Yet, often the value of soil, a largely non-renewable resource, is not always appreciated.

The famous scientist, Gallileo said, *"What greater stupidity can be imagined than that of calling jewels, silver, and gold 'precious,' and earth and soil 'base'? People who do this ought to remember that if there were as great a scarcity of soil as of jewels or precious metals, there would not be a prince who would not spend a bushel of diamonds and rubies and a cartload of gold just to have enough earth to plant a jasmine in a little pot, or to sow an orange seed and watch it sprout, grow, and produce its handsome leaves, its fragrant flowers, and fine fruit."*



Soil should be regarded as a material that has chemical composition, structure and supports plants and living organisms (PB).

Unfortunately, the careful use and management of soil has not been a high priority for many people. In fact, there is evidence that the thin layer of soil that we all depend on, in many areas of Europe and beyond, may be increasingly threatened by a range of human activities.

For this reason, the European Union has decided to protect soil in the same manner as water and air by developing a strategy to safeguard this vital resource. To this end, the European Commission, supported by the Council of Ministers and the European Parliament, has agreed to develop a Thematic Strategy for Soil Protection.

One of the primary aims of the **Soil Atlas of Europe** is to support the European Soil Thematic Strategy by providing comprehensive information about European soil and raising awareness of issues affecting soil. The approach adopted by the policy makers of Europe is to ensure that soil is used in a sustainable manner so that future generations may inherit a viable environment and, if possible, find it in an even better condition that it is at present.

Soil protection aspects exist in Community legislation in a scattered manner. Requirements aimed at preserving soil quality can be found in the Common Agricultural Policy, in different pieces of environmental legislation and in product legislation. So far there is not at EU level any instrument specifically addressing the protection of soil. In the 6th Environment Action Programme[1] (EAP) among the priorities set for the conservation of biodiversity and natural resources, the Community took the commitment of addressing soil alongside water and air as an environmental media and as a non renewable resource to be preserved, hence taking the commitment of developing a Thematic Strategy for the protection of soil.

As a first step in this process, the Commission adopted on 16 April 2002 a Communication[2] "Towards a Thematic Strategy for Soil Protection". This Communication highlighted the need to introduce, in a more systematic manner, soil protection aspects in other Community policies. It also identified the major threats to soil in the enlarged EU, i.e. erosion, organic matter decline, contamination, loss of biodiversity, salinisation, compaction, sealing, floods and landslides. The Communication was followed by a very wide and inclusive public consultation with Member States in 2003 and 2004, soil scientists, industry, environmental NGOs and other stakeholders in order to develop the basis of soil policy in the EU.

Taking into account the very local nature of soil and its huge variability, the Commission has always sought to ensure that the right level of intervention is reached for soil protection (some measures are better adopted at local, regional and national level, some at Community level), that any EU-wide action would have to reflect the soil variability and allow for sufficient flexibility to apply a customised approach for the different types of soils and that Community action would be based as far as possible on existing schemes. This approach, coupled with the results of the comprehensive public consultation, will be building blocks for the Thematic Strategy that the Commission envisages to propose by the end of 2005 in order to meet the challenge of establishing a long term soil protection policy to ensure a sustainable use of soil in the EU.

[1] Decision 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme, OJ L242, 22.07.02, p.1

[2] COM(2002) 179 final

We are preserving the environment for future generations through measures to protect soil (EM).

Another goal of this atlas is to educate. Many people have no knowledge of soil nor the important roles that it plays. This atlas aims to explain and show, in a non technical manner, how soil is created, the properties of soil and their relevance to society, the different soil types that are found across Europe and how soil is classified and mapped.

The core of the atlas is a striking series of maps illustrating the varying patterns of different soil types occurring across Europe. The maps show, for the first time, the distribution of the soil of Europe through a new soil classification scheme, the World Reference Base. The atlas also displays a series of maps showing the relevance of European soil types in a global context.

The maps that make up this atlas are based on information provided by the European Soil Bureau Network: a collection of organisations from all the countries of Europe that are responsible for mapping and managing soils. The European Soil Bureau collaborates with the European Commission to provide relevant information to policy makers. The soil information is stored in digital or computerised form. This allows us to create maps using special computer programmes, known as geographic information systems.

As you will see in the following pages, subtle variations in landscapes, land use and geology can lead to local variations in soil types. The maps of the atlas show the broad regional patterns across Europe of the major soil groups that are generally characteristic of that area.

The atlas concludes with an examination of the major threats to soil across Europe. The goal of the European environmental policy is to reduce the pressure of these threats on soil.

Although the text has been written in English, the atlas aims to show the diversity and richness of soil across all Europe. If you are interested in discovering more about soil in the other languages of Europe, please consult the Bibliography Section at the back of the atlas.

After reading this atlas, we hope that the content helps you to understand better how the product of the complex interactions between climate, geology, vegetation, biological activity, time and land use leads to the creation of the valuable resource we call **Soil**.

Weathering of rocks in mountains produces sediments that are transported downstream by erosion to create fertile soil in the lower parts of the landscape (PZ).

What is soil?

There is an old Chinese proverb that states:

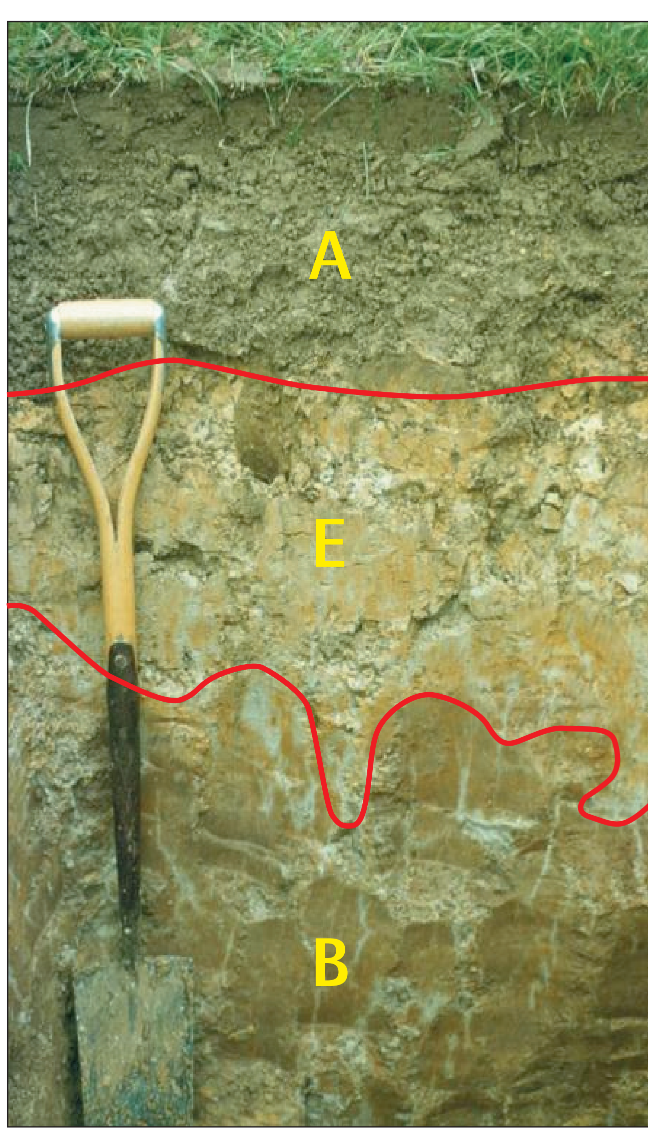
"Man…despite his artistic pretensions and many accomplishments, owes his existence to a thin layer of topsoil …and the fact that it rains".

When different people refer to 'The Soil' they usually have rather different ideas of what this means. To the gardener or farmer, soil is the upper few centimetres of ground that is cultivated and nurtured to produce crops. To the engineer, it is the 'overburden' or unwanted loose material at the ground surface that needs to be removed to provide a more stable foundation upon which to work. To the geologists it is the loose 'unconsolidated' material overlying the rocks they study. However, to the vast majority of the human race living in cities and towns, soil is simply the 'dirt' or 'dust' to be cleaned from their hands or the vegetables that they buy to eat. Many large supermarket retailers in the western world now do this before putting them on display in order to make such produce 'more attractive and presentable'.

In fact, soil is all of these different things. Soil is the living, breathing skin of our planet and it is affected by, and is the result of, the many and varied interactions that occur between the atmosphere, as governed by climate and weather patterns, the biosphere, that is the local vegetation and animal activities including those of man, the geosphere, the rocks and sediments that form the upper few metres of the Earth's solid crust. Those of us who study soil have a definition for it. We say 'soil is any loose material at the surface of the Earth that is capable of supporting life' and these life-supporting functions have been understood for a very long time.

What is soil made of?

All of us have come into contact with soil at some time in our lives and most are familiar with such terms as clay, sand or peat. In reality, soil consists of a complex mixture of mineral and organic particles that represent the products of weathering and biochemical processes that break down the local rocks and sediments into individual grains of increasingly smaller sizes and also break down the dead vegetation and organisms that fall on or remain within it. When we handle the soil, the fact that it usually stains and moistens our fingers, shows that it also holds different amounts of water and chemicals and the amounts of these that can be held by the soil are determined by the size and origin of the mineral and organic particles present. The two other final components that make up the soil are the organisms, both plants and animals, that live (and die) within it and the air that enables them to live there.



The soil in profile

Soil is the product of various environmental weathering processes that operate on geological materials on the Earth's surface over a period of time. If we dig down into the soil to about 1 or 2 metres depth and look at the vertical section revealed, we notice a number of roughly horizontal layers that look slightly different. These layers are the result of the local environmental weathering processes and they have colour, physical structure and chemical characteristics that differ significantly from those of the underlying rocks and sediments. Soil scientists call the layers 'soil horizons' and, as a means of shorthand and easy communication, assign letters of the alphabet to distinguish the different types.

Know Your A, B, C!

When a soil pit is dug and the vertical profile of the soil examined, normally, an uppermost layer that is darker than those beneath can be recognised. This is the 'topsoil' or 'A horizon' which contains most of the organic material within the soil; hence its darker colour. It is the engine room of the soil where most of its biological and chemical activity occurs. If the topsoil layer is removed by erosion or human activity, most of the soil's ecological potential goes with it. Although the topsoil layer will regenerate over time, if left undisturbed, it may take hundreds of years for its full original potential to be restored.

Below the dark-coloured topsoil are one or more brighter coloured layers; the 'subsoil' or 'B horizons'. These layers contain much less organic material (making them different in colour) but are still exploited by plant roots and soil animals that use the water, air and nutrients stored in them. They are usually brown or reddish in colour because they contain iron oxides weathered from clay minerals in the soil.

These photographs show how soil profiles can differ quite radically in their appearance depending on their position in the landscape (JH).

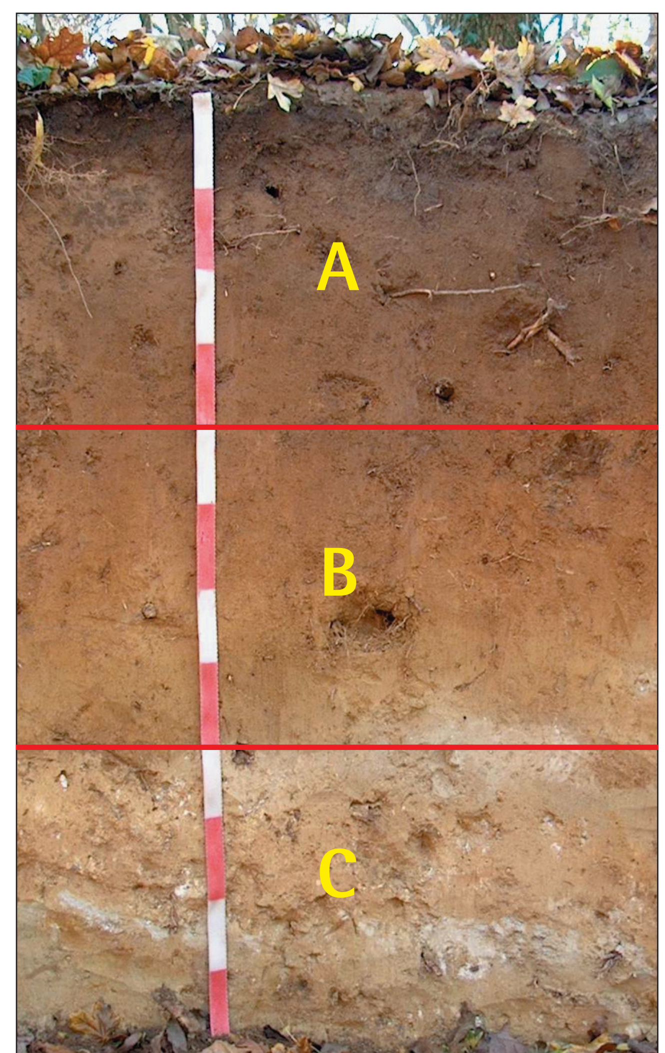
The profile on the right, a Cambisol under woodland, shows a classic A-B-C sequence of soil horizons, with colour differences reflecting the relative distributions of organic matter and iron oxide produced by the weathering of minerals in the soil (JH).

In contrast the profile on the left, a Stagnic Luvisol under pasture, shows an more complex sequence of A-E-B horizons. Colour differences again reflect changes in the distribution of organic matter and iron oxide minerals, with the paler coloured E horizon containing less clay or iron oxide than the A or B horizons. However, superimposed on these basic colour differences is a 'mottling' effect caused by periodic waterlogging of the soil as a result of the impermeable clayey nature of the B and C horizons (JH).

In many European soil types, between the dark coloured 'A' and brighter 'B' horizons, is a pale coloured layer. This horizon has a smaller content of very fine material such as clay, organic matter, nutrients and chemicals such as iron than either the overlying A or underlying B, hence its paler colour. Such layers, from which some soil components have been 'leached' out, are known as 'eluvial' or 'E' horizons and usually represent the most impoverished parts of the soil profile with respect to biological activity and nutrient availability.

Towards the base of the subsoil, the soil structure gradually dies out as the factors affecting its development decrease in influence.

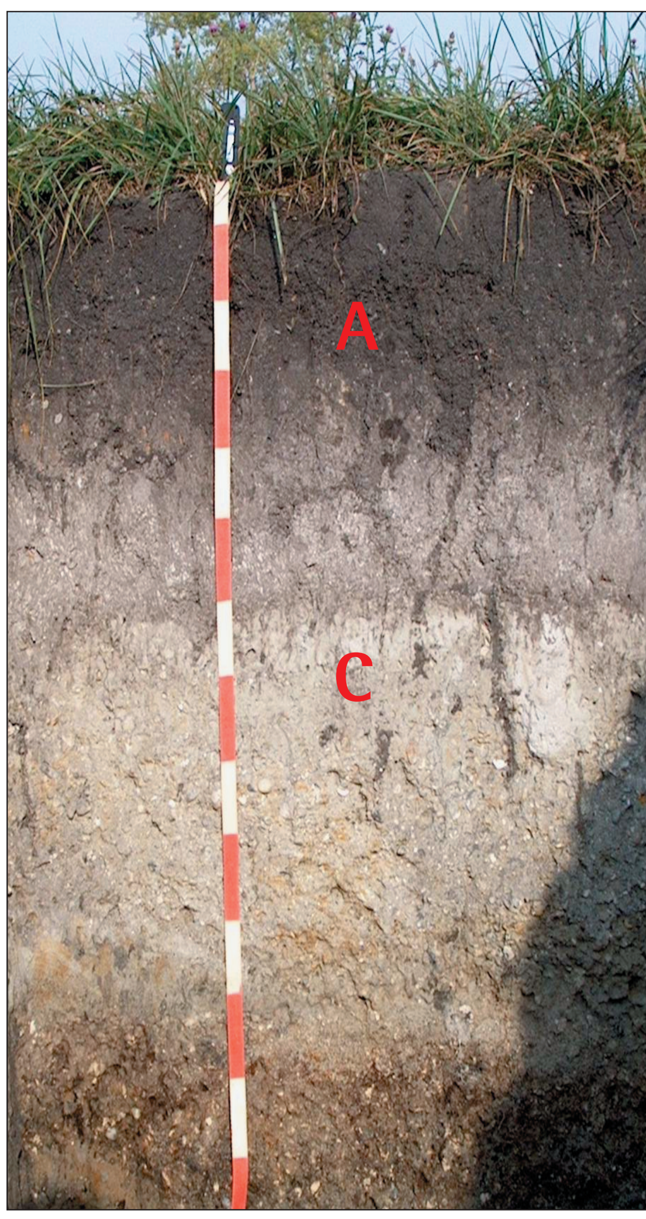
Eventually a layer is reached where the influence of environmental weathering processes is minimal, either because there is hard rock present or because there has not been enough time for the processes to have a significant impact or because the layer is too far from the land surface to be affected. This layer is called the soil 'substrate' or 'C horizon' or 'soil parent material' and has either no structural development or shows joints and bedded layers characteristic of rock formations.

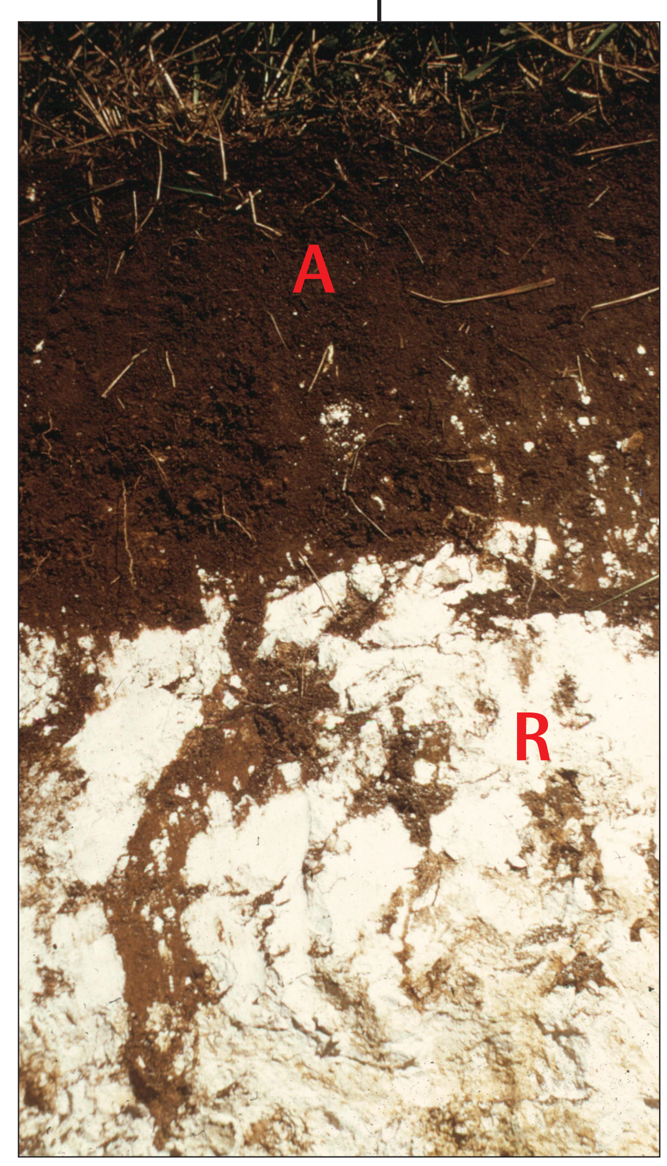


What is soil?

Within the A, E and B horizons, various clods, aggregates and grains of different sizes can be seen. These are the building blocks of the soil that together form its architectural fabric or 'structure'. Soil structure determines the amount and rate of water and air movements. The structure of the soil results from natural processes such as seasonal cycles of wetting and drying and freezing and thawing and, especially in the topsoil, from interactions between the mineral components and substances derived from living and dead plants and animals.

Structure in the upper parts of the soil is also affected by human activities, in particular, agricultural cultivations, vehicle trafficking and building operations. However, it is also important to remember that simply walking over the soil surface alters its soil structure and the more frequently this happens the greater the alteration.





These photographs show two very different soils in a mountain landscape.

The profile on the right is a Leptosol where the dark, organic-rich A horizon lies directly over an R horizon of calcareous (lime rich) rock (IB).

In contrast, the profile on the left, a Fluvisol on the river floodplain is a deep soil, with a thick, organic-rich A horizon merging downwards into the C horizon of relatively unaltered rich river silt over sands and gravels. The lower parts of the C horizon are periodically waterlogged by a rising groundwater table and show a similar grey and orange 'mottled' effect to that in the E horizon of the soil shown on the previous page. Because of their fertility and reliable water supply, such river floodplain soils were usually the first to be exploited for agriculture by humans (JH).

Do you say earth, soil or dirt?

According to the Oxford English Dictionary, the word "**soil**" is an Old English term coming from the Latin, *solium*, meaning seat but used to imply ground (*solum*).

The word soil can also be used in a derogatory sense to mean something is damaged or unclean, "these clothes are soiled". However, this sense of the word soil has a different derivation, coming instead from the Old French word *suiller*, which in turn is derived from the Latin for pig, *sus*. More than likely, people who tended pigs generally had unclean clothes and were identified by their soil-covered clothes. Over time the differences in meaning were forgotten.

Although the term "**dirt**" is an often used as a substitute for soil, the word dirt often implies an unclean appearance. The word dirt originates from the Old Norse, *drit*, meaning excrement. The common meaning of the words dirt and soil probably relate to the use of farmyard manure as a fertilizer to improve soil. Crops would be planted in soil fertilized by dirt.

The term, "**earth**" has a Germanic or Saxon origin that gave rise to the Old English word, *eorthe*, while the word for wet soil, "**mud**," also has a Saxon origin that became the Old English word, *mot*, meaning a bog or a marsh.

Key Facts You Should Know About Soil

- Soil makes up the outermost layer of our planet and is formed from rocks and decaying plants and animals.
- Soil has varying amounts of organic matter (living and dead organisms), minerals, and nutrients.
- An average soil sample is 45 percent minerals, 25 percent water, 25 percent air, and four percent organic matter. Different-sized mineral particles, such as sand, silt, and clay, give soil its texture.
- Topsoil is the most productive soil layer.
- Ten tonnes of topsoil spread evenly over a hectare is only as thick as a one Euro coin.
- Natural processes can take more than 500 years to form 2 centimetres of topsoil.
- In some cases, up to 5 tonnes of animal life can live in one hectare of soil.
- Fungi and bacteria help break down organic matter in the soil.
- Earthworms digest organic matter, recycle nutrients, and make the surface soil richer.
- Roots loosen the soil, allowing oxygen to penetrate. This benefits animals living in the soil. They also hold soil together and help prevent erosion.
- A fully functioning soil reduces the risk of floods and protects underground water supplies by neutralising or filtering out potential pollutants and storing as much as 3,750 tonnes of water per hectare.
- Soil scientists have identified over 10,000 different types of soil in Europe.
- Research indicates that soil captures approximately 20% of the man-made carbon emitted to the atmosphere annually.

So many differences

The characteristics and vertical arrangement of soil horizons can vary greatly from place to place, often over surprisingly short distances. This is because of the diverse range of surface geological materials across Europe, combined with the geographic variability of the environmental weathering processes that alter them.

In addition to this variability, the environmental weathering processes vary over time, both in the short term with seasonal weather and vegetation cycles and in the long term, as climate and land use patterns change in response to external drivers.

It is this complexity across Europe that gives rise to the incredible diversity of soil. The same type of geological material will have a different arrangement of soil horizons in a Mediterranean environment than it will in Scandinavia or under intensive lowland agriculture than under ancient woodland.

This then is soil; a dynamic body that acts as the home to a myriad of organisms, responds to the changing seasons and weather patterns with associated changes in its organic, liquid and gaseous composition and, chameleon-like, gradually changes to reflect its local environment.

The role and importance of soil

Soil is the vital natural habitat that regulates our environment and responds to the pressures imposed upon it. Ignored by the majority of us, soil carries out a number of key environmental tasks that are essential to our well-being:

• Soil is the medium that enables us to grow our food, natural fibre and timber.

The most productive agricultural soil is to be found along the major river valleys of Europe such as the Danube, Rhine, Seine and Ebro, their estuaries and also on the glacial plains of northern Europe where ice age winds have deposited a layer of fine rock-dust to form fertile 'loess' soil. The well drained but often thin soil formed on the chalk and limestone plateaux of southern and eastern England and the Paris Basin form some of the most extensively exploited cereal growing areas of Europe.

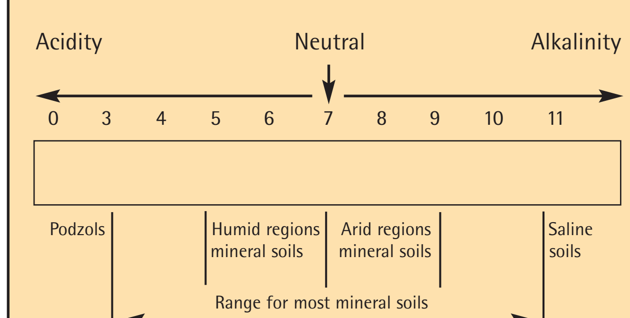
Sunflowers growing in France. Soil health and quality are fundamental issues for the production of crops and foodstuffs (EM).

• Soil is the natural filter and reclamation centre where potential pollutants are neutralised and broken down and excess water is re-distributed to surface or ground water.

The photographs above and to the right (JH) show the drainage from two soil types with very different filtering potential. The sediment-laden drainage shown above is derived from a soil that has been leached over time. Rainfall percolating through its weakly structured upper layers detaches clay-sized material and removes it from the soil through field drains along with associated agro-chemicals. The uncontaminated drainage shown on the right is derived from a soil with much more stable structure. Both soil types occur in the same field!

What is pH?

When soil scientists describe soil they often refer to it as being acid or alkaline or having a certain pH value.
The pH index is a number used to express the concentration of hydrogen ions in a solution. This number indicates the degree of acidity. The scale is from 0 to 14, with a neutral soil having a pH of 7. Alkaline soils will range from pH8 to pH14 (strongly alkaline) while acid soils will range from pH6 to pH2 (strongly acid).



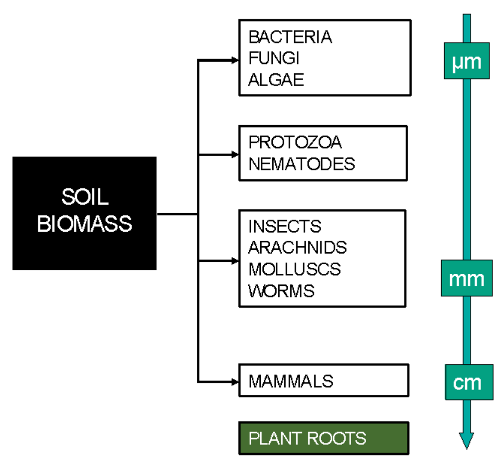
Soil can absorb much of the rain that falls on it but the amount varies according to texture, structure and vegetative cover. Well structured loamy soil under grass or woodland acts like a sponge and can absorb as much as 40% of its volume as water. However, under some types of intensive cropping, the regular use of heavy machinery can compact the soil preventing rain from infiltrating and increasing surface runoff. In other cropping systems such as vineyards, maize and sugar beet, part of the field surface may remain bare at times when rainfall is most common or heaviest. Under such conditions, the surface structure of the soil quickly collapses and a surface seal or 'cap' forms. This prevents rain from entering the soil and increases surface runoff. Sandy and silty soil with small amounts of organic matter is particularly vulnerable to surface capping.

Increased surface runoff and decreased soil storage potential can significantly increase the likelihood of 'flash' flooding from intensive rainfall. Surface capping also reduces the amount of rainfall that infiltrates the soil and eventually replenishes the underground water resources stored in porous rocks ('aquifers'). In some cases it may increase the amount of rain that is rapidly moved to the surface water network, resulting in a more rapid rise of river levels in response to rainfall and possibly even increasing the likelihood of river flooding.

Increasing numbers of floods in recent years have demonstrated the paramount importance of effective and integrated management of land resources in the protection of the environment and the citizens. The loss of soil resources to urbanisation is a key factor in enhancing flood events. The picture on the left shows flooding in the valley of the River Uck in Southern England, November 2000, which caused extensive damage to buildings in the nearby market town of Uckfield (AT).

The role and importance of soil

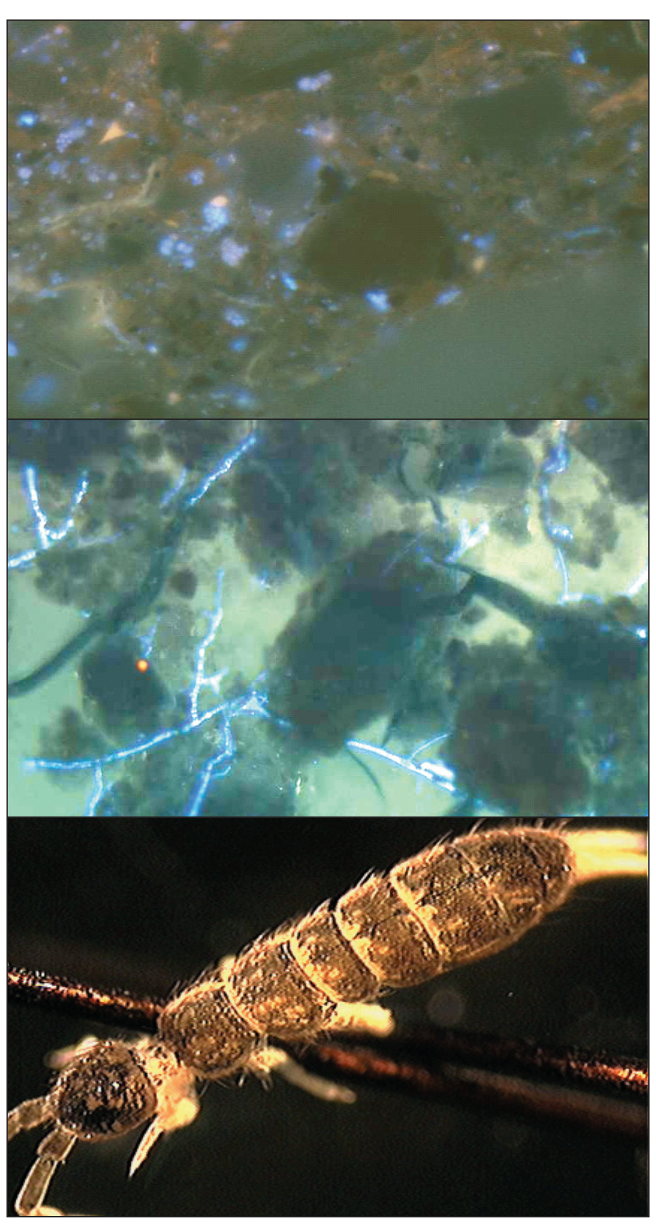
• Soil is the environmental engine room where dead plant and animal tissues and other wastes are re-cycled to provide nutrients for the growth of new life. The incredible variety of organisms that inhabit the soil and the diverse biological resource they represent is only just beginning to be understood



Life in soil and associated size ranges (KR).

A vast quantity and range of life resides in most soil types. The total weight of organisms below a temperate grassland can exceed 5 tonnes per hectare, equalling or exceeding the above ground biomass. A few grams of such soil contain billions of bacteria, hundreds of kilometres of fungal hyphae, tens of thousands of protozoa, thousands of nematodes, several hundred insects, arachnids and worms, and hundreds of metres of plant roots.

If soil is the engine room, then the soil biota form its biological engine. They are involved in most of the key soil functions, driving fundamental nutrient cycling processes, regulating plant communities, degrading pollutants and helping to stabilise soil structure. Soil organisms also represent a crucially important biotechnological resource, with many species of bacteria and actinomycetes providing sources of antibiotics.



The photographs above show some of the meso- and micro-organisms present in an arable soil: top – bacteria (stained light blue) in worm casts (KR); middle – fungal hyphae forming mycelium (branch like structure) along the soil pore network (KR); bottom – tiny insects known as springtails (order Collembola), usually less than 4 mm long, are abundant in soil throughout the world, feeding on living and dead plant material (DC).

Soil biodiversity reflects the mix of living organisms in the soil. Our knowledge of the diversity of life within the soil compartment is still at a basic level. The above picture shows (from top left, clockwise) a bacterial colony (KR), a nematode (KR), a centipede (IB) and an earthworm (KR).

The huge numbers of soil organisms are matched by extreme biodiversity, particularly at the microbial scale. Soil bacterial communities alone comprise some tens of thousands of species and many hundreds of other species types are also present. Below ground biodiversity always exceeds that above ground. Such extreme diversity is thought to originate in the complexity of the soil structural architecture where the pore networks that form the living space for below ground life propagate from the macro- to the micro-scale. These subterranean labyrinths provide physical protection to organisms, but can also isolate them from other organisms within the network. Each isolated community evolves independently, leading to the generation of biodiversity.

At present we are not sure how important such biodiversity is with respect to sustaining soil functions. However, it is likely that in many semi-natural ecosystems, complex inter-relationships have developed between the myriad of soil organisms present. Reducing soil biodiversity will inevitably change the balance of these relationships and may even impair functioning of the ecosystem.

• Soil protects our buried heritage of archaeological and historic remains from damage and depletion.

Much of the evidence of our European heritage remains buried within the soil, awaiting study by archaeologists and palaeo-ecologists. The degree of preservation of such remains depends very much on the local soil conditions.

Waterlogged or very acid soil with low levels of oxygen has very little microbial activity and provides an ideal environment for preserving organic remains. Any disturbance of these environments, such as the drainage of wetlands or the ploughing and levelling of burial mounds, changes the conditions and leads to rapid decay and loss of the material. In more freely draining and well aerated soil, most organic remains have completely decayed and the only evidence of their presence is a dark stain within the soil. The principal archaeological remains that occur are mineral artefacts - stone structures or tools, pottery, and metal objects.

Archaeologists use these artefacts and the layers in which they are preserved, to reconstruct the communities that produced them and the environments in which they lived. But to do this the soil layers must remain undisturbed.

In 2004, Swiss scientists discovered Europe's largest living organism - a fungus called Armillaria ostoyae (honey fungus) covering 35 hectares (approximately the size of 35 football pitches) growing in a national park near the town of Ofenpass. The fungus prevails as an underground network of connected filaments, and is apparent above-ground when it produces mushrooms that emerge from the soil, often concentrated around the roots of trees. The largest living organism ever discovered is another species of Armillaria found in the Malheur National Forest in Oregon, covering 890 hectares (JD).

Hittite statues (below) made of relatively soft basalt and limestone were discovered intact after being buried under wind blown and fluvial soils. In comparison to statues of a similar age, found in the same area, that were left on the surface, the fact that these artefacts were preserved in soil meant that they were protected from the effects of thousands of years of weather (SK).

• Soil provides the foundation upon which we construct our buildings, roads and other infrastructures.

Gravel is used throughout the world in the construction of roads and buildings (EM).

• Soil: a vital role.

The soil functions described on these pages are vital to life on Earth but not all soil types can carry them out to the same extent and some are far more susceptible to the collapse of a function when stresses are placed on them.

A type of clay soil, known as a Vertisol, shrinks strongly when it dries out and swells equally strongly as it becomes wet. Seasonal cycles of wetting and drying can result in significant soil movement, even at depths of over 1metre, particularly if there are large contrasts between wet and dry seasons. Such soil is inherently unstable and can cause significant problems for building foundations unless special engineering solutions are put in place. However this type of soil is also fertile and can store adequate moisture to sustain crop growth. From the functional perspective therefore, Vertisols have a good, sustainable potential for food, fibre and timber production but a poor and costly potential for maintaining stable foundations. Ideally, new building developments and infrastructure should avoid Vertisol areas, which should be maintained as agricultural, recreational or semi-natural land.

A clear understanding of the functional capability and potential of different soil types is thus vital for planning the sustainable development of our environmental resources. We should never forget that soil is the beating heart of the ecosystem. Remove the soil and life within that ecosystem will collapse.

Ped, Clod and Sod!

In the English language, a number of words are used to describe "lumps" of soil.

- A ped is an aggregate of soil particles formed by natural processes.
- A clod is a lump of soil formed by artificial means such as ploughing or digging.
- A sod is a piece of soil that is held together by a layer of grass. Sods are often used to prepare or repair lawns, football pitches and golf courses.

Soil forming processes

Soil in Europe varies tremendously

Some soil types are deep and allow roots to penetrate up to three metres, whereas some possess strongly cemented horizons or acid subsoil that inhibit rooting. These differences arise from the interaction of local environmental processes acting upon the soil fabric.

Such ***soil forming processes*** are determined by climate and organisms (both plants and animals) acting on the local geological surface materials over time. Additionally, the basic influences of climate and organisms are modified by both the slope of the land and human activities. The interplay between all these factors creates the soil forming processes that gradually change the geological materials into a soil with distinct and well defined horizons.

Climate and vegetation are responsible for the creation of the major soil groups. These groups are known as zonal soils and cover large areas. Examples of these soil groups include the Podzols of the coniferous forests of northern Europe and the Chernozems of the grass steppes in Ukraine. Slopes and different parent materials can modify or change the soil type completely from what is expected from the climate and vegetation conditions. Some soil profiles can develop horizons that are impermeable for plant roots in landscapes where soil conditions favour deep rooting. Histosols can develop in depressions in an otherwise well drained landscape. Such soil is called an intra-zonal soil and might be erratically distributed as islands in the zonal soil.

Time is an important consideration since the soil forming factors must act for a considerable period to develop the mature soil profile with well expressed soil horizons. Some soil forming processes, such as gleying (water-logging), might occur within a few years while podzolization might take centuries to develop a mature Podzol.

Finally, humans play an important role in soil formation by manuring, irrigating, draining, liming and ploughing the land.

The **dominant soil processes in Europe** are typical for humid temperate, semi-arid and sub-tropical climates. The major soil forming processes acting on well drained sediments are humus formation, leaching, weathering, clay migration, clay destruction and podzolization, while on imperfectly draining sites they consist of gley formation, precipitation of pyrite, peat formation and in the semi-arid areas, salinization (high salt levels). The following texts describe these processes.

Soil processes in well drained sediments

Humus formation

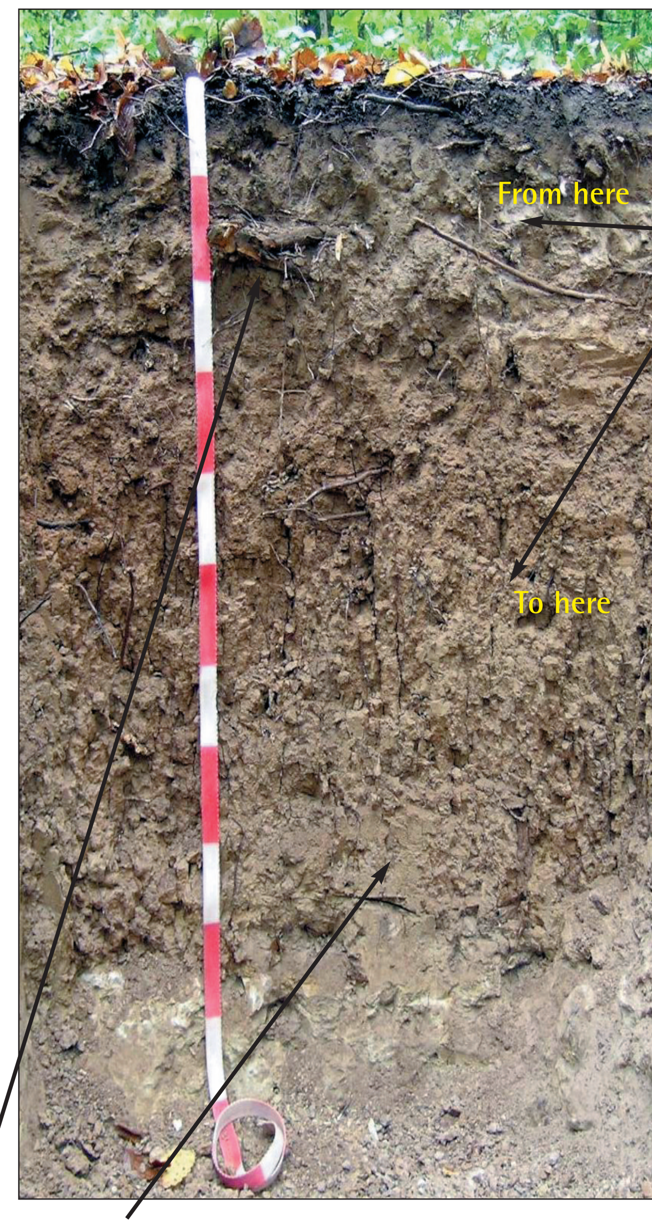
Plant cover plays an important role in soil formation and nutrient turn over. Plants extract nutrients from the soil water solution to build up organic material. After death the plant material will decompose in the soil through the actions of micro-organisms like bacteria, fungi and animals such as earthworms and ants. Through decomposition, water and carbon dioxide are released and humus is formed.

If the soil is slightly acid to slightly basic then the decomposition of the organic matter is relatively rapid and earthworms mix up the humus with the mineral soil and a type of organic matter called *mull* is formed. A thick mull layer is found in the mid-latitude continental part of Europe where low annual precipitation, cold winters with little snowfall, hot summers and a precipitation maximum in spring guarantee the development of deep humus and nutrient rich mull horizons, sometimes more than one metre thick. Chernozems, some of the most fertile soil in Europe, are formed under such conditions.

In acid soil, fungi dominate the conversion of plant remnants to humus. The decomposition rate is slow and the worms that should mix up the sediment and the humus are scarcer. The organic matter remains on top of the mineral soil forming a *mor* layer. This can be divided into three parts. At the top a *litter* layer consisting of newly fallen leaves. Below that is found the *fermentation* layer with partly decomposed litter from previous years and at the base is the humus layer with fully decomposed plant remnants without any macroscopic evidence of its origin.

Mor – an organic-rich, acidic layer lying on the surface.
Mull – a surface layer in which mineral and organic matter are intimately mixed.
Moder – an intermediate phase between mull and mor where decomposition is greater than a mor but not as advanced as a mull.

The photograph below shows the profile of a typical well drained soil under temperate forest and shows evidence of the main soil processes described in the surrounding texts: humus formation, weathering, leaching and clay translocation (EM).



Weathering

Below the sediments on which soil has developed we usually find solid rock. In fact all sediments are derived from solid rock by a process known as weathering. There are in principle two types of weathering, physical and chemical.

By physical weathering, rocks disintegrate without changing their chemical composition. Typical examples of these processes are the splitting of rocks by freezing and thawing or the daily warming by the sun and cooling during the night.

In chemical weathering, the minerals in the rocks decompose and new minerals are formed. Minerals such as feldspar, mica, augite, hornblende and olivine (known as the primary silicates) which are stable at higher temperature and pressure than found at the Earth's surface will slowly disintegrate to form secondary silicates such as clay minerals (e.g. kaolinite, illite, vermiculite and smectite), iron and aluminium hydroxides, carbonates and readily available nutrients such as calcium and potassium. As described earlier, the clay minerals are very important for plants as they retain nutrients and favour root growth.

The various forms of iron oxides are often responsible for the colour of the soil. In central and northern Europe, goethite is the dominant mineral giving the soil a brown or yellowish-brown colour. In the warmer Mediterranean region, hematite coatings are formed (a process known as rubefaction) giving the soil a characteristic red colour.

The weathering intensity is highest at the surface and decreases with depth. Thus, the amount of iron oxides formed will decrease with depth meaning that the colour of the subsoil will be lighter at the base of the profile.

Leaching

Most of Europe is characterized by a climate that provides a precipitation surplus during some part of the year (i.e. where rain and snowfall are greater than evaporation rates). This surplus fills up the soil water 'reservoir' which might have been depleted during a summer. The remaining surplus of rainfall during autumn and winter percolates down through the soil to form groundwater or feed rivers.

When passing through the soil, the water quickly dissolves easily soluble salts such as chlorides, nitrates, sulphates and, more slowly, the carbonates. In northern Europe there is evidence that about 10,000 years are needed to dissolve the calcium carbonate in the uppermost one metre of glacial tills. The calcium carbonate is leached as calcium and bicarbonate ions. In the drier part of Europe they can be re-precipitated further down the soil profile as calcium carbonate to form a *Calcic* horizon. In more humid parts they are leached to the groundwater. As long as calcium carbonate is present, the pH of the soil is about 8 (see Page 12) and the soil will often be whitish or light coloured. When all the calcium carbonate has been dissolved and leached away, the pH will fall and calcium, magnesium, sodium are leached from the surfaces of both clay minerals and humus to be replaced by hydrogen, aluminium and iron. When this process ends, the pH will be around 4 and the soil is referred to as being acid. Under extreme conditions, soil pH can be as low as 2.0 to 3.0 which is regarded as very acid (e.g. acid sulphate soil). For agricultural use such soils will often be limed in order to raise the pH to a more acceptable level for plant production and by ploughing and liming, the *mor* layer will be turned into a *mull* layer.

A leached soil profile. Calcium carbonate is being leached from the upper part of the profile and redeposited as a whitish horizon lower down the soil (ED).

Soil across Europe!

While this atlas is written in English, the maps show the rich variety of soils across Europe. This box lists the translation of the word "soil" in the languages of Europe and shows the cultural and linguistic diversity in our people.

Albanian: Dhé
Bulgarian: Pochva
Croatian: Tlo
Czech: Půda
Danish: Jôrd
Dutch: Bodem
Estonian: Muld
Finnish: Maaperä
French: Sol
German: Boden
Greek: Edafos (Χώμα)
Hungarian: Talaj
Irish Gallic: Talamh
Italian: Suolo
Latvian: Augsne
Lithuanian: Dirvožemis
Luxembourgish: Boudem
Maltese: Ħamrija
Norwegian: Jord
Polish: Gleba
Portuguese: Solo
Romanian: Sol
Romany: Phuv
Russian: Pochva (почва)
Serbian: Zemlja
Slovakian: Pôda
Slovenian: Zemlja
Spanish: Suelo
Swedish: Jord
Turkish: Toprak
Welsh: Pridd

Humus formation and weathering are common phenomena that affect all soil types. All other processes described in this section are particular and form different kinds of soil against the background of humus formation and weathering.

Soil forming processes

The movement of clay particles

One of the most common soil forming processes is the movement of clay particles from one soil horizon to another. This process is known to soil scientists as translocation and involves the mechanical transfer (eluviation) of clay particles from the topsoil by percolating water and the re-deposition of the clay particles below (illuviation) on the surfaces of soil particles or in wormholes.

There are some physical and chemical conditions that should be fulfilled before the process starts. The pH of the soil should be between 5 and 7 where it is believed that the soils structure is so weak that aggregates easily break down and release single clay particles to the soil water. The percolating water can then transport the clay particles downwards if a continuous coarse pore system has developed. Such a system will develop if dry seasons alternate with wet seasons. In that way the soil will shrink during the dry season and develop cracks which form pathways for the movement of the clay particles during the wet season. The clay will accumulate where the cracks end and the water movement almost stops or where the water penetrates into the dry aggregates and the clay particles are filtered at the ped surfaces forming clay layers called *cutans*. Clay particles are very small, normally less than 2 micrometres.

The above profile shows a soil with clay illuviation. At the top of the profile, we can see the darker plough layer overlying a light brown horizon. Clay minerals have been leached from both these horizons to the ones below (HBM).

Clay destruction

As described above, the movement of clay within a profile leads to a soil with less clay in the topsoil than below. Similar clay distribution can be found in soil where the clay in the topsoil has been destroyed rather than removed. This process is believed to happen in soil with an acid topsoil (pH < 5). It is not clear how common this phenomenon is in Europe but it is believed to be very active in tropical regions.

On the other hand, the destruction of clay particles in former clay rich Bt-horizons is common in many parts of Europe. In this case, the clay on the ped surfaces is redistributed or disintegrated leaving behind tongues of silt and sand that cut into the former clay enriched horizon. At the end of such a process, the Bt-horizon can totally disappear.

The profile on the right illustrates the result of the processes of clay translocation and destruction. Most of the clay minerals will have been illuviated or degraded in the pale coloured horizon. The horizon below is enriched with clay but even there in parts the clays are still being broken down leaving a variegated appearance. A small podzol is forming in the clay depleted upper horizon (HBM).

Podzolization

Sandy sediments are rather common in the northern part of Europe and especially in Scandinavia. In these areas, huge coniferous forests dominate the landscape and podzolization is the normal pedological process in the sandy glacial deposits. The continuous leaching of the soil in combination with a slow and incomplete decomposition of the organic matter fallen on the ground form a distinct mor layer.

Organic acids from this layer destabilize the iron and aluminium oxides in the soil, which are then leached by the percolating water, leaving behind sand grains with whitish colours as the colouring caused by the mineral goethite has gone. Below a depth of about of about 50cm, an illuvial B horizon forms. The uppermost part of this horizon consists of a black humus rich layer that sits on a reddish-brown horizon with enhanced iron content. These two horizons can be strongly cemented by the iron, aluminium and carbon coatings on the grains and is then referred to as an 'ortstein'.

Below, a classic Podzol soil profile on arable land clearly showing the white leached horizon, followed by dark humus rich and iron rich zones. The uppermost greyish layer is caused by the mixing as the result of ploughing of humus material and white sand grains (HBM).

Soil processes in imperfect drained areas

Gleying

When it rains, water percolates through the soil. In many cases, this water drains away. However in some cases, due to a slowly permeable subsoil or the presence of a barrier to drainage, the water has no escape route and forms a 'perched watertable within the soil.'

In some soil types, temporary or permanent groundwater can be found at relatively shallow depths (< 2 m). This groundwater is mainly due to restrictions on drainage outfalls, the location of the soil in depressions in the landscape that collect water or in marshy areas near to the coast.

A shallow groundwater strongly decreases the movement of gases in the soil because oxygen and carbon dioxide diffusion in waterlogged pores is very slow compared to air filled pores. If organic matter is present in the waterlogged soil horizon the metabolic activity of the micro-organisms will create an oxygen deficit and a state known as reducing develops. In these conditions, ferric iron (Fe^{3+}) is converted to the more soluble, and therefore mobile, ferrous iron (Fe^{2+}). Since the ferric oxides are responsible for giving subsoils their characteristic yellowish-brown or reddish-brown colours, their disintegration into ferrous oxides will give the soil a distinctive greyish or bluish colour. However, in some of the larger pores where some oxygen may remain, mottles of rust-coloured material indicate the presence of oxidizing conditions.

Above, a well developed pseudogley profile (see text below for explanation) (JH).

In soil science, two basic types of gley are widely recognised, **pseudogley** and **groundwater gley.**

Where water is held temporally above a slowly permeable or impervious horizon, a surface water gley or pseudogley is formed (see above picture). This type of gley is characterized by the presence of bleached ped surfaces and root channels while the interior of the peds is enriched by ferric iron. Pseudogleys can develop in any location in the landscape where perched watertable will develop in periods with precipitation surplus (i.e. high rainfall events) and disappear in periods when the soil dries out.

In Europe, this sort of perched watertable will typically develop during the autumn and winter months and will disappear during spring. With the development of intensive farming and the need to improve land for agricultural needs, many soils with pseudogley characteristics will today be described as drained and the pseudogley may be regarded as a relict feature.

Soil forming processes

Groundwater gleys develop in depressions in the landscape where permanent groundwater can be found at shallow depth. The groundwater gley is characterized by the chemical deposition (precipitation) of ferric iron on ped surfaces or in root and worm channels. The interior of the ped is bluish because of ferrous iron (described in the previous page). In some gley soil, the mineral ferrodisulphide or pyrite can be found (iron pyrites is commonly known as Fools Gold).

If drained, the groundwater gley is a useful soil for farming but some soil processes might give rise to problems if drainage is actually carried out! The high sodium (salt) content in coastal soil types may destabilize the soil structure after drainage, the soil structure will collapse and the agricultural value remains low. The oxidation (rusting) of pyrite after drainage can cause the release of sulphuric acid leaving the subsoil with pH of around 2 (very acid). This condition will not only give serious problems for farming but also environmental problems due to *ochre* pollution (a combination of iron oxide and clay minerals, used as a pigment to produce red, brown or yellow paints).

A groundwater gley. Note the presence of distinctive blue-grey colour and the red mottles denoting the re-deposition of iron oxides in the presence of oxygen (HBM).

Peat formation

Very wet areas with permanently anaerobic conditions (no oxygen) give rise to peat, the dark, unconsolidated, fibrous material that we buy in garden centres and supermarkets in order to grow plants. There are two major types, moor and fen peat, which develop in different ways.

Fen peat develops in river valleys, flood plains and lakes when the water becomes so shallow that plants such as the reed, *Phragmites*, invade the water body. When the plants die, their waterlogged remains cover the soft deposits in which they grow and, over time, become peat. The pH of fen peat is neutral to mildly alkaline due to the presence of calcium, potassium, magnesium and sodium found is the sediment of rivers and streams. As these watercourses also transport clay, silt and sand deposits, the fen peat will often have a substantial mineral content.

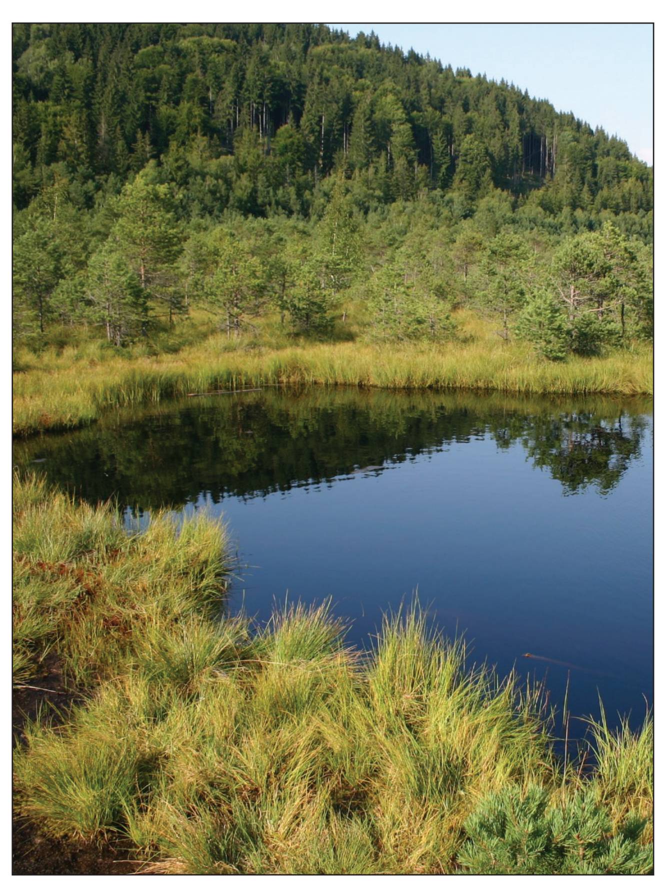
Moor peat develops in the uplands and areas with high rainfall. As rainwater is poor in nutrients, acid conditions develop and, as we have previously seen in the Podzols, a slow decomposition of plant debris occurs. As a consequence, organic matter accumulates and forms blanket peat or raised bogs. These raised bogs, which can also form on a fen peat, are very acid as they do not obtain the nutrient inputs from water courses as happens in the fen peat. *Sphagnum*, a type of moss, is one of the most common plants in raised bogs forming a fibrous soil with a pH often below 3.

This picture shows about 80 centimetres of fen peat overlaying the olive-grey coloured limnic deposits from a former lake. The high organic content of the peat soil is clearly visible. Peat is formed under cool, humid climatic conditions. The word "fen" means an area of wooded swampy lands where the underlying sediments are lime-rich boulder clays (deposited during the last ice age). The term is derived from an area in eastern England (HBM).

Peat

- Peat is a very important source of fuel in many northern countries (e.g. Ireland, Scotland, Russia). Compared to coal, peat has a much lower calorific value and produces a lot of smoke when burnt. Given the right geological conditions and time (millions of years), peat deposits may eventually change to lignite or even coal.
- Many people refer to 'peat bogs'. A bog is the general term for an expanse of waterlogged spongy ground composed of decaying plant remains. The well-preserved remains of trees are frequently discovered within peat bogs. These remains give an indication of a former landscape, often drier and warmer than the present, which was overwhelmed by wetter and cooler conditions.

The photograph below shows a typical landscape of an upland peat bog. Small pools like the one shown in the photograph will slowly fill up with decaying plant remains and silt. The water in such areas often appears brown because it contains high concentrations of dissolved organic compounds that come from the decomposition of vegetation (ED).



Salinisation

In semi-arid regions, salt affected soil may develop in depressions and in alluvial plains where groundwater levels are high. In such areas, water is "sucked" to the surface due to capillary actions. Due to the heat of the sun, the water will evaporate leaving behind deposits of salt in the surface layer. Crusts of salt (a process known as encrustation) will often develop on the surface.

Some saline soil types are naturally occurring but others have developed due to agricultural practices. Irrigation has provided the right conditions for salt encrustation to occur as the salt in the irrigation water is left behind in the soil when the irrigation water is used or transpired by the plants.

The above photograph shows a salt affected soil. Such a soil is known as a Solonetz or Solonchak. The white salt crystals in the dark horizon are clearly visible (EM).

The photograph below is a good illustration of surface salt crusts and salt tolerant vegetation (EM).

What is a salt?

Most people know from their school days that the chemical formula for common salt, the substance we add to our food and what makes the sea salty is sodium chloride or NaCl.

However, a salt is actually any chemical compound formed from the reaction of an acid with a base element where the hydrogen of the acid is replace by a metal. Hence, sodium hydroxide and hydrochloric acid react to create a salt, sodium chloride, and water.

$NaOH + HCl = NaCl + H_2O$

If solutions of salts are allowed to evaporate, then the salt is deposited as crystals.

Examples of other salts include copper sulphate, lead nitrate, magnesium chloride and magnesium sulphate (the latter is better known as Epsom Salts).

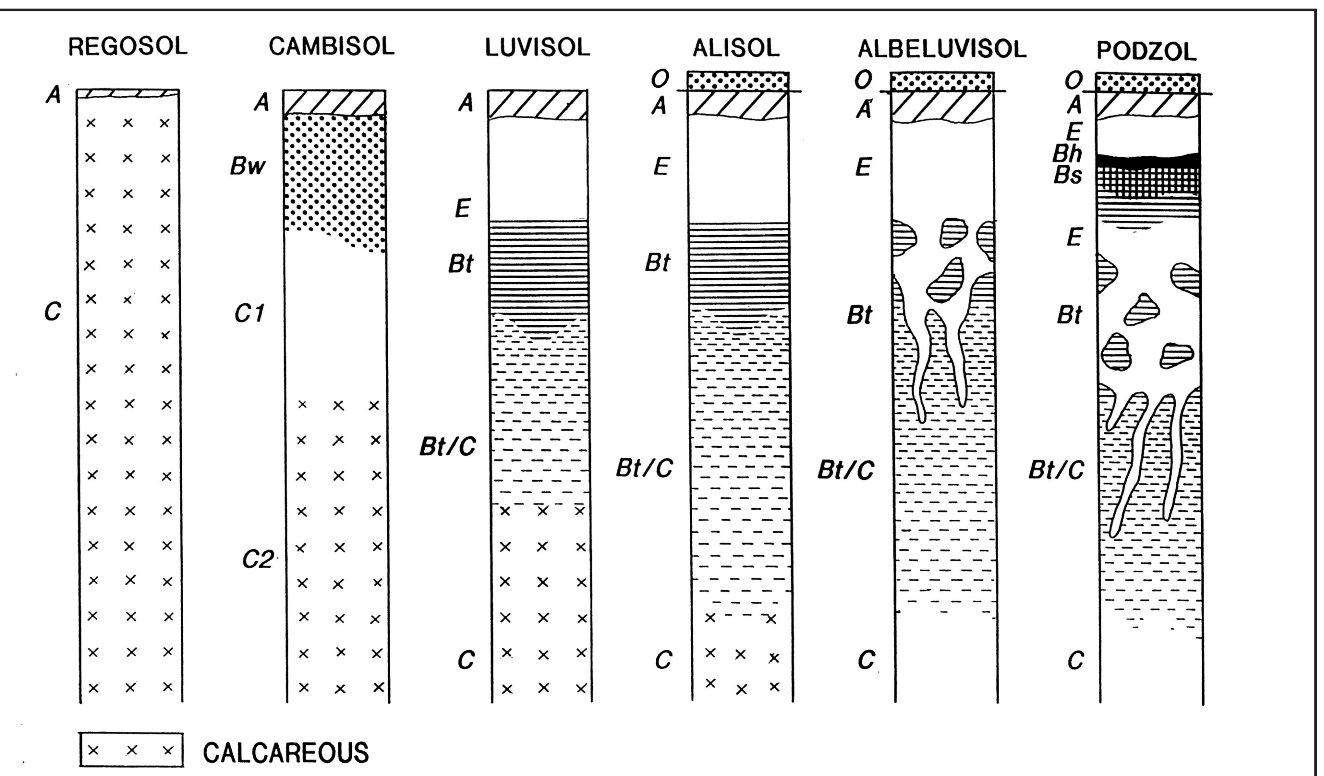
Soil forming processes

Soil processes on well drained sediment in relation to time

The processes described in this section form the most common types of soil found in Europe.

In some sediments only a few of the processes described in the previous pages will be active while in other soil types or locations, several processes could be running simultaneously or following each other. The figure below illustrates how different soil processes can produce a succession of soil types in a loamy calcareous sediment.

Initially, we have the newly deposited sediment. Only a shallow humus layer has developed and free calcium carbonate is still to be found close to the surface. This soil is known as a **Regosol**. After some time, the calcium carbonate will be leached from the top part of the soil, a deeper mull layer has developed and the weathering of the primary silicates and the formation of iron oxides has created a strong coloured B-horizon just below the mull layer. The soil is now called a **Cambisol.** The continuous leaching moves the calcium carbonate front further downwards, the pH drops to about 6 and clay illuviation starts. We have now a nutrient rich **Luvisol** but the leaching will continuously remove the base elements from the soil. This will make the profile so acid that it will be classified as an **Alisol**. At this stage the soil is so acid that the clay in the illuviated horizon will disintegrate or be redistributed to other parts of the profile and tongues of silt and sand will cut into the clay illuviated horizon. This is referred to as an **Albeluvisol**. Finally, the leaching will enable an iron pan to develop and the soil turns into a **Podzol**.



Soil in relation to man

The natural soil reflects the history of the soil forming factors. Therefore, in a natural state each soil type has some distinctive characteristics. For example, a Podzol is an acid soil with a mor layer. This will normally be true in forests but ploughing and liming on arable land will remove the mor layer and turn it in to a mull layer about 30 cm thick and with a pH of around 6. A wet soil at the base of a slope with gleyic characteristics can be drained. Rivers can be straightened thus lowering the water table in the adjacent soil. Gley features in such areas express a former state and as such behave as a natural well drained soil.

Histosols will often disappear when drained because the peat layer will physically shrink due to water loss followed by the decomposition of the peat due to oxidation.

Other soil types with poor agricultural value due to low nutrient levels can be improved through fertilizing and manuring to become a high yielding soil. In Denmark, liming of the strongly leached, loamy Saale till has raised the pH by about 1.5 units in the plough layer but at a depth of 1.2 m the effect of the liming has gone. On the calcareous, loamy Weichsel till, the leaching of the topsoil has lowered the pH to about 5, but at a depth of 1.2 m the pH is about 8. On arable land the liming has increased the pH to about 7 in the topsoil, whereas at the depth of about 1 m the pH on the arable and forest land is the same (about 8).

This changing of the chemical characteristics of the soil can stop, reverse or reactivate some of the pedological processes. Podzolization stops immediately when the mor layer has been removed and the pH raised to about 6 while clay migration, which mainly happens in slightly acid soil, can revitalize when lime is applied.

In the drier parts of Europe inadequate irrigation of the fields can lead to salinisation while agriculture in mountainous areas can lead to severe soil erosion. This latter aspect has been demonstrated in historical time in the Mediterranean area. Mature soil with well developed horizons can been washed away completely and replaced by bare rock.

Man's activity has also created new soil types such as urban soil, soil in huge waste deposits and, in former times, the famous *plaggen* soil (see section on Soil and Archaeology later in the Atlas).

Due to the creation of gardens and parks, soil in urban areas can be modified significantly compared to its original natural state (EM).

Imperfectly and poorly drained soils in relation to topography.

The series of photographs below illustrates a topographically related sequence of soils known as a **catena** (a term derived from the Latin meaning a chain); soil profiles are linked together when traced down a slope from the ridgeline to the valley floor. Soils change character according to slope angle and drainage conditions.

On the crest of the landscape we find thin soils with underlying parent materials very close to the surface. These are usually Regosols. On the slope towards the valley the precipitation surplus can leach nutrients laterally or vertically and leached profiles can be found if the local conditions permit the formation of deep soil. In the valley bottom we can find groundwater gley at shallow depths. In the centre of the valley, peat formation has taken place and thick layers of fen peat have developed. The nature of the parent material can be important.

A shallow soil. (HBM) — *Leaching. (HBM)* — *Waterlogging leading to gleyic conditions. (HBM)* — *A fen peat. (EM)*

The soil in your garden

The closest most people ever get to soil is when they are in their garden. Without soil, no flowers would grow, there would be no grass for the lawn and no fruit or vegetables for the kitchen! How does someone find out what type of soil they have in their garden?

As you have seen in the previous pages, soil is made up of humus (organic matter) and various proportions of three different sizes of particles: clay, silt and sand. The particular combination of soil particles and organic matter, together with the local climate, parent material and previous vegetation cover determine the type of soil in your garden.

A loam, which is a mixture of sand, silt and clay in rougly equal proportions with a moderate level of organic matter, is often regarded as the perfect garden soil!

Topsoil

When you look at bare ground, all you see is the topsoil. As you have seen in the previous pages, you'll see a clear boundary between the topsoil and subsoil if you dig a deep hole in your garden. Around a new house, it's possible that there will not be any topsoil at all. In this case topsoil must be brought in. It's worth checking this because if the topsoil layer is only a few centimetres thick, the subsoil can cause the gardener problems.

What kind of soil do you have?

Stand by a patch of bare soil in your garden with a watering can. Tip the water on to the soil. If the water drains away immediately, then you have a permeable soil. If the water lies on the surface for a while then the soil may be clayey or compacted.

You can also find out what kind of soil you have by touching it. Take a good handful of soil, moisten it and squeeze it in your hand. If you are left with a ball of sticky material then you have a clay soil. Sandy soil feels gritty and falls apart when you open your hand. A peaty soil feels spongy while a loam or a silty soil feels smooth and stays in a ball but not as strongly as the clay soil.

Another test for soil type is to see how the soil particles settle in water. Take a large transparent glass or plastic jar. Add a handful of soil, stir well and leave to settle over night. How the container appears in the morning can reveal the texture of the soil:

- Sandy Soil: sand particles have sunk to the bottom and the water is clear.
- Silty Soil: water is cloudy, thin layer of sediment on the bottom.
- Clay Soil: water is still cloudy, very little sediment on the bottom because clay particles take a long time to settle.
- Loam Soil: fairly clear water, layered sediment on the bottom with finer particles on the top.
- Organic Soil: organic material floating on the surface, water cloudy and a small layer of sediment on the bottom.
- Lime-rich soil: layer of white gritty fragments on the bottom, water has a pale-grey or milky colour.

What problems will your soil cause?

- If you have a clay soil- water logging when it's wet.
- If you have a sandy soil – drying when it does not rain.
- If you have a lime rich soil – dry and some plants will not grow in your garden.

Is your soil acid?

An important property of a garden is whether the soil is *acid, alkaline* or *neutral*. From a chemical point of view, the acidity of a soil is determined by the number of hydrogen atoms (ions) compared to hydroxyl ions (a compound of oxygen and hydrogen - OH). High levels of hydrogen ions causes acid soil while the reverse gives alkaline soil. Equal concentrations of hydrogen and hydroxyl ions give a neutral soil.

What you see growing in your garden depends on the type of soil (AJ).

Rhododendrons thrive in acid soil (EM).

Neutral soil, usually clays, has a pH of 7. Acid soil, such as peat, has a pH of 6 or less while alkaline soil, often found in lime-rich areas, has a pH of 8 or more.

The acidity of soil influences the plants that will grow in your garden because the pH level of the soil determines how plants absorb nutrients and control the presence of toxic elements. In alkaline soil, a number of key elements such as iron, manganese and zinc become soluble (dissolved in water) and are washed out of the soil while the levels of certain metals, such as molybdenum, become higher. In acid soil, aluminium and iron are soluble in sufficient quantities to be toxic to the growth of plants.

Most plants prefer a pH between 6.5 and 7 (slightly acid or neutral). Within this range, nutrients are most easily available to plants. Plants that prefer acid soil conditions will not thrive in alkaline soil, and may even die. The opposite is also true.

Plants such as rhododendrons or camellias growing in the garden indicate acid soil. Saxifrages, yew trees and certain clematis indicate alkaline soil. Whilst several conditions, including sunlight, water and soil acidity can affect the colour of flowers, in general, acidic soils produce blue blooms in hydrangeas whilst alkaline soil makes them pink.

A more accurate way of establishing the pH of a soil is to use a testing kit, available from garden centres.

Improving the soil in your garden.

Very few people are lucky enough to have "the perfect" soil in their garden. Many people have a heavy clay soil or nutrient poor sandy soil. There are a few simple ways to improve the quality of the soil in your garden.

Digging and incorporating well-rotted organic matter can significantly improve soil structure. The easiest source of organic matter is a compost heap where garden waste (grass cuttings, leaves, twigs, straw) can be stored.

In the case of a clay soil, sand and organic matter can be added to improve the texture of the soil.

In many cases, the soil can lack sufficient nutrients. Plants do not grow very well. In this case you may need to add some fertilizer or "plant food" to your soil. Fertilizers are basically divided into two groups:

- Organic: from natural sources like plants, animals.
- Inorganic: manufactured 'chemical' feeds or mineral deposits.

Plants don't care where their nutrients come from but from a gardeners' point of view, organic fertilisers have an advantage because they encourage soil bacteria, which help to keep soil healthy.

Traditional gardens in Europe have a 'kitchen patch' for growing fruit and vegetables for home consumption (RJ).

The soil in your garden

Adding organic matter to your soil: making your own compost

Buy or make a simple composting bin (four stakes and some chicken wire) to contain your compost. Try to choose a site on grass or soil so that earthworms can move in and out of the compost heap.

Start off by adding a layer of coarse material e.g. (twigs and branches) and build up the heap by adding layers of garden and kitchen wastes.

Woody stems should be cut up into small pieces. Weeds that can re-root from small pieces must be left out to die for several days before adding to the heap. Grass cuttings should be mixed with coarser material to allow air circulation and to stop them from turning into a wet mass.

Vegetable waste from the kitchen is good to add too. But cooked food and meats should be avoided because they may attract vermin. Old woollen and cotton clothes, newspaper and cardboard cut into pieces will compost if soaked and mixed in. Wood ash from fires and even waste from the vacuum cleaner can all be composted

To help decomposition, moisten the heap. If you want to speed things up, intersperse with layers of manure from a local farm. Try not to let the compost heap dry out completely or it will not rot down. Keep heat in and rain out by putting on a lid of newspaper, plastic sheeting or carpet. Chemicals to accelerate decomposition are not essential but they do add bacteria and enzymes that improve composting. It is the action of these micro-organisms that generates the heat which is so beneficial in the composting process, especially for killing weed seeds.

When the heap begins to shrink in size and starts to cool, take out the contents, shake up any compressed matter and return them to continue the composting process. When the compost is brown and crumbly you can add it to your soil as needed.

A simple garden compost bin that produces cones of rotted organic material when lifted (AJ).

Farmyard manure, a mix of straw and animal excrement, is often used by gardeners to raise soil organic levels and improve soil texture (AJ).

The finished product: a rich, fertile compost (EM).

A European deep burrowing earthworm, Aporrectodea longa (Lumbricidae), a sign of healthy soil (EM).

Earthworms

A good indication of a healthy soil is the presence of earthworms in your garden. An earthworm is a long, creeping animal, with a soft, segmented body. They have no legs but instead are covered in hairs or bristles that help them to move. They breathe through their skin, which must remain moist to absorb oxygen from the air.

Earthworms have existed for about 600 million years. There are about 3,700 species of oligochaetes (terrestrial earthworms); many are so small that they are invisible to the naked eye.

Earthworms are hermaphrodite, which means they do not need another worm to reproduce. They lay eggs which hatch as little worms. Worms can live for up to ten years.

Soil as a source of food

Plants absorb around thirty different types of nutrients and minerals through their roots. For this to happen, the nutrients and minerals must be dissolved in water – another reason why plants must be watered.

The main soil nutrients for plants are nitrogen (N), phosphorus (P) and potassium (K). Soil also contains several minor elements that are only needed in minute amounts.

In nature, leaves and plants decompose and return nutrients to the soil, maintaining the natural balance. However, by weeding and tidying the garden, the remains of plants that would naturally rot down are removed and, over time, the nutrient reserves of a soil are depleted. This is why people add fertilizers to their garden.

Many people still grow their own vegetables in the garden – how does fertilizer help the soil? (EM)

The value of worms for soil is that they are able to eat in excess of their own weight in organic waste, soil and minerals and excrete their own weight in castings daily, which makes compost and enriches the soil. The worms living in one hectare can break up about 100 tonnes of soil per year. They don't eat living plant tissue and so do not hurt plants either. Some people even keep them as pets, feeding them on kitchen scraps just so the worms can make compost for their gardens.

If you accidentally cut an earthworm in half while gardening, only one part of the worm will die. The piece with the saddle (the fatter, pink part) will survive. When the temperature is very cold or very hot, worms are able to survive by burrowing deep into the soil.

- The longest earthworm in the world is the African Giant Earthworm, which can grow up to 6.7m long.
- Earthworms avoid light.

The most common garden fertilizers contain a mixture of N:P:K. If a packet is labelled 6:4:4, it means that in every 100 grams of fertiliser, there is 6 grams of nitrogen and four grams each of phosphorus and potassium.

The N:P:K ratio helps you choose the right fertiliser. If the ratios are about the same, it is a general-purpose fertiliser and will aid all round plant growth. If the fertiliser has a higher ratio of:

- Nitrogen - it will encourage leafy growth
- Phosphorus - it will encourage root development
- Potassium - it will encourage fruit and flower production

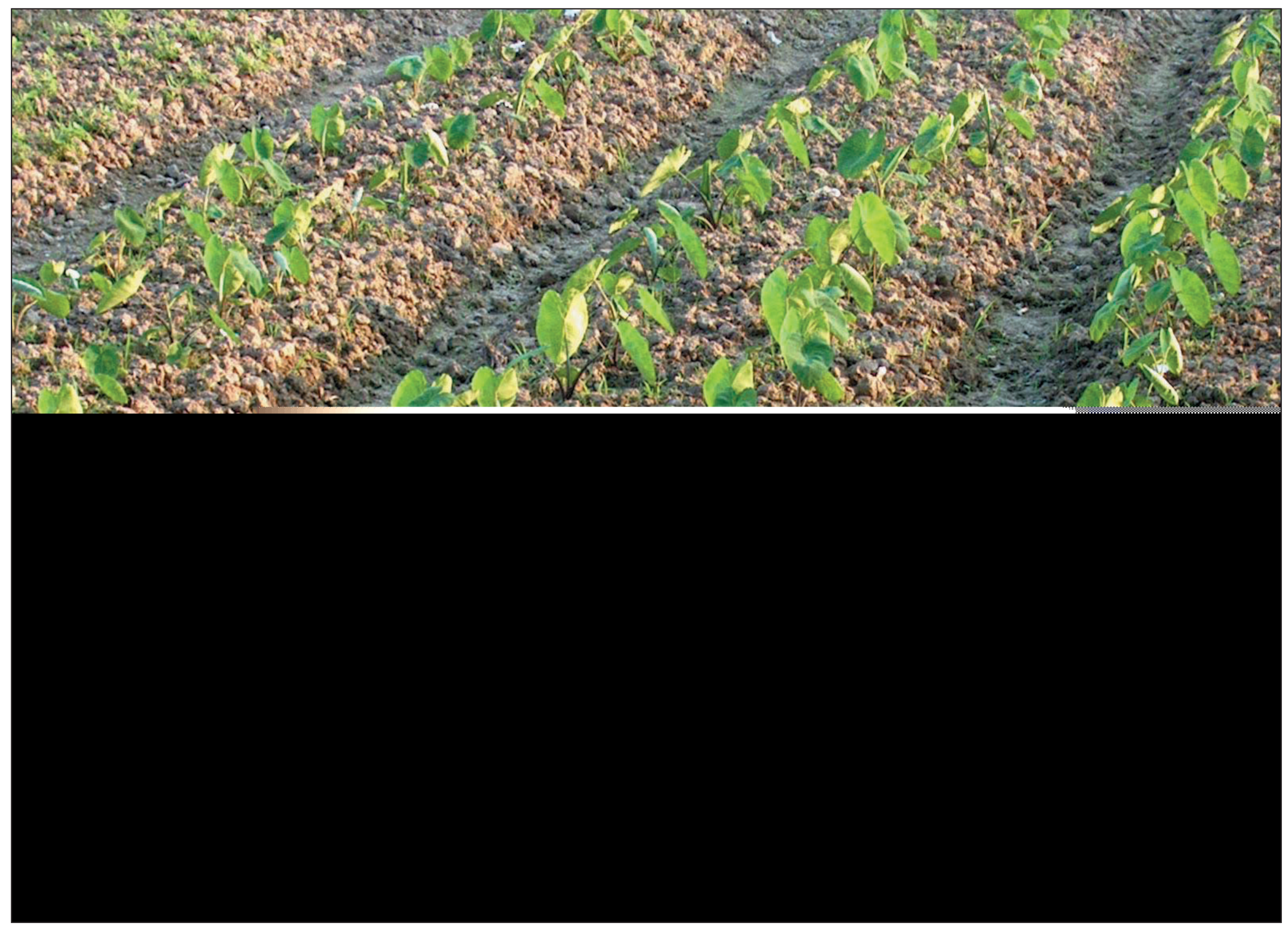
Soil and agriculture

Soil is the medium that enables us to grow our food, natural fibre and timber. Virtually all vegetation, including grasses, arable crops, shrubs and trees, need soil for the supply of water and nutrients and to fix their roots. It is not an understatement to say that soil is one of the key issues on which agriculture is based and, thus, fundamental to the existence of human society.

Agricultural soil is a precious and limited resource, whose value has frequently been built up by man during decades or even centuries. Irreversible degradation of soil implies not only ruining the main asset of the current generation of farmers but also reducing the farming opportunities of future generations. Therefore, there must be a sustainable use and management of agricultural soil, with a view to safeguarding the fertility and agronomic value of agricultural land.

The most productive agricultural soil is to be found along the major river valleys of Europe such as the Danube, Rhine, Seine and their estuaries. It is interesting to note that all societies have long recognised the productivity of these dark and base-rich soils. Their location with respect to available river and ground water ensure their high productivity.

Productive agricultural soil can also be found on the glacial plains of northern Europe where ice age winds have deposited a layer of fine rock-dust to form fertile 'loess soil'. The well drained but often thin soil formed on the chalk and limestone plateaux of southern and eastern England and the Paris Basin form some of the most extensively exploited cereal growing areas of Europe and, until recently, produced more grain than Canada



World food supplies are affected by the quantity and quality of soils, which in turn are influenced by the proper management of soils, especially the use of fertilizers, pesticides, irrigation and land tillage practices (EM).

On the floodplain of the River Po in northern Italy, one can find the largest area of rice production in Europe. Every spring the paddy fields are flooded with snowmelt from the nearby Alps to start the cultivation of the rice crop, much of it destined for the famous risotto dishes of Italy (EM).

However, not all agriculture is confined to lowland plains or river valleys. One should not forget the famous wines and olive oils produced in some of the drier areas of Europe. Vineyards and olive plantations are usually situated on the well draining soils of the Mediterranean basin and central Europe. These soil types, usually light coloured, are often quite fertile and will respond very well to various types of soil management procedures (e.g. irrigation).

Olive trees growing in southern France (AJ).

In some parts of Europe the pressures on soil are so great that terrain, normally considered not to be suitable for farming has been adapted over time for agricultural use. The reclamation of coastal land and subsequent management through drainage and fertilizer allowed Dutch engineers to create the polders. In Ireland, farmers carried cartloads of seaweed to raise the organic content of fields to improve the quality of pasture while in many mountainous parts of Europe, steep slopes were terraced to create fertile ledges for crops and animals.

The picture below shows the Cinque Terre region of Italy. Productive agricultural land was so scarce in these coastal villages that extensive terraces were constructed and agricultural soil was developed by the local farmers on the steep slopes. The soil of the Cinque Terre has now been classified as a World Heritage Site by UNESCO (EM).

Throughout many parts of Europe, especially in Scandinavia, forestry is the major form of land use. Extensive tracts of conifers, growing on acid Podzols, are managed, generally in a sustainable manner, to provide us with softwoods for furniture and paper. One should also bear in mind the other products of the forests, such as berries, mushrooms and the opportunities for game and recreation, generate significant revenue in several countries. In Finland, the annual revenue generated by the collection of forest berries is estimated at around 11 million Euros. This figure does not include private harvestings. Currently, there is considerable interest in forests and, especially, forest soil for storing carbon dioxide from the atmosphere as a mechanism to combat global warming due to greenhouse gases.

The acid Podzol soil of northern Europe does not immediately give the impression of an agricultural soil. However, Podzols support large areas of silviculture and associated activities (EM).

While agriculture and forestry soil are fundamental to our livelihood and are subject to threats originating from other sectors, there is widespread concern about the consequences of several agricultural practices on soil quality. The excessive use of fertilizers and pesticides can have a dramatic impact on soil biodiversity and possibly, on human health. The spreading of sewage sludge, the organic rich by-product of waste water treatment plants, as a fertilizer has been halted by many European countries and is the focus of intensive research due to concerns about heavy metals and other pollutants. Use of heavy agricultural machinery can cause the soil to compact and lose the capability to store water.

Fluvisol, found on recent alluvial deposits, is often a highly fertile and agriculturally productive soil (EM).

The Common Agricultural Policy of the European Union already provides farmers with opportunities for soil protection. A number of agri-environmental measures offer opportunities for the build-up of soil organic matter, the enhancement of soil biodiversity, the reduction of erosion, diffuse contamination and soil compaction.

These measures include support to organic farming, conservation tillage, the protection and maintenance of terraces, safer pesticide use, integrated crop management, management of low-intensity pasture systems, lowering stock density and the use of certified compost.

Potatoes growing in Holland. Careful management of soil resources is of paramount importance in the sustainable management of the environment (EM).

Soil and cultural heritage

Many of the activities of our ancestors can still be recognized through detailed studies of the soil. In fact, the soil is one of our main sources of information on the history of man before he was able to write.

Soil as a medium for preserving artefacts and treasures

When digging the soil for gardening, farming or constructing buildings, artefacts, treasures or other evidences of human activities are often exposed. Different soil types preserve these remains in various ways.

In wet soil types such as Histosols and Gleysols, the lack of oxygen (anaerobic state) slows down the decomposition of organic matter. In these soil types the remains of animals can be found with hunting marks from arrows or spears. Well preserved human bodies have been excavated from moors and bogs. In some communities, people were executed and buried in the moors as a religious act. The anaerobic conditions preserve the bodies very well and several thousands of years later they are excavated with skin, flesh and clothes still present and sometimes it is even possible to investigate the food content in the stomach giving us an idea of what they were eating just before they died. Wooden constructions, such as poles for bridges, boats and wooden tools can be preserved giving us valuable information on the level of technology at that time.

In well drained soil such as Chernozems, Luvisols and Podzols, organic artefacts will decompose rapidly while metallic items such as weapons and ornaments can be preserved for longer periods. The aggressiveness of the soil to metal can vary among soil types and the climatic conditions. Acid soil is slightly more aggressive, rusting iron artefacts faster than neutral to slightly acid soil. In wet humid climates, decomposition rates are faster than in a cold arid environment. Pottery, on the other hand, seems to be rather stable in all soil types.

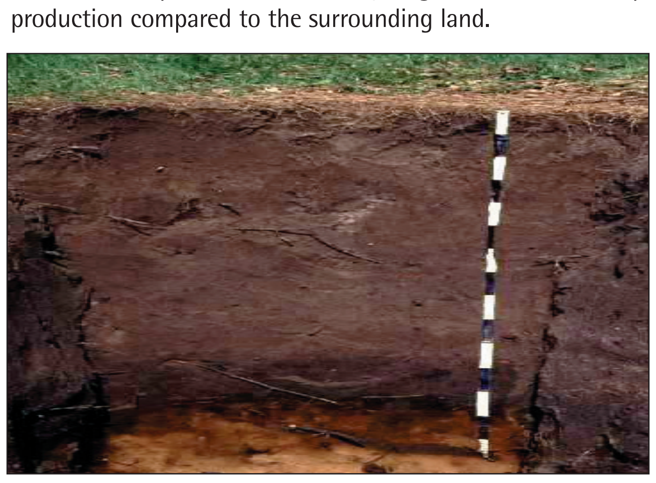
Treasure found in the soil – this ceremonial helmet was discovered in a 7th Century Anglo-Saxon ship burial in Sutton Hoo, UK (British Museum).

The soil profile as an archive

The development of characteristic horizons in the soil can provide valuable information on human life in ancient times.

Agriculture practices

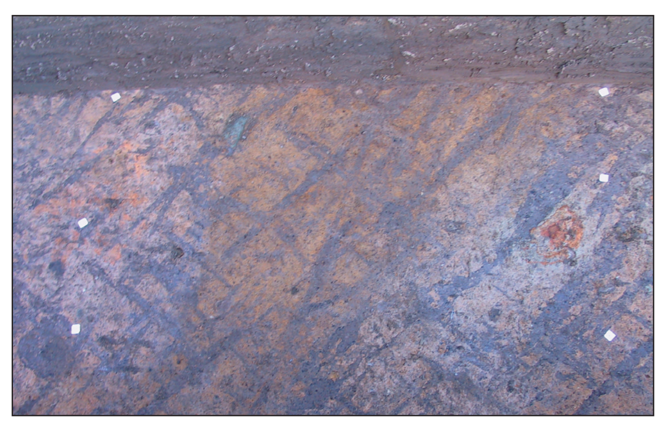
Past farming practices can be recognized in the soil profile. In northwest Europe, especially in the Netherlands and Germany, a special man-made soil type, known as ***plaggen*** soil, has developed as a result of a special agricultural system. On the strongly leached, acid sandy outwash plains and moraines, Podzols have developed underneath a vegetation cover of heather (*Calluna vulgaris*). The farmers used the heather and the uppermost centimetre of the soil as bedding in the stables. The dropping from the animals, mixed with the bedding, was later used as manure on the nearby fields, slowly building up a thick humus rich soil layer rich in nutrients and soil water. These fields provide a relatively high and stable crop production compared to the surrounding land.



A typical plaggen soil with a very deep man-made humus layer (from the Netherlands) (HBM).

The Neolithic Age burial mound in Anglesey, UK, is approximately 6000 years old. Buried archaeological objects have been used to study soil formation in many European countries (AJ).

Careful study of the soil at the border between the uppermost humus coloured soil horizon and the yellowish-brown subsoil below can provide important information on previous human activities. In *plaggen soil*, spade marks are a distinct feature while in other areas orthogonal marks from ploughing with ards (oxen-pulled ploughs) are common. In some regions, humus coloured marks can be found indicating the positions of postholes for wooden houses thus telling us about the location of former settlements.



Criss-crossing plough furrows made about 3300 years ago in Denmark (HBM).

Soil processes in burial mounds

Some man-made soil constructions, such as burial mounds, allow certain soil processes to operate that lead to well-developed soil horizons. These horizons, under special circumstances, can change the chemical environment in such a way that extraordinary conditions can develop for the preservation of human bodies and grave goods.

In the South Scandinavian Bronze Age (1300-1400 BC), many thousands of burial mounds were constructed in Denmark, southern Sweden and northern Germany. They were about 15 metres in diameter and 3-4 metres in height but some were much larger with diameters up to 70 metres. They were built of sods over one or a few stone beds on which oak log coffins containing the bodies of presumably high ranking people were placed.

A modern experiment to reconstruct a Bronze Age burial mound that develops iron pans (HBM).

In some cases, as the result of a special construction method for burial mounds, iron pans have developed both above and beneath the core of the mound and, in this way, totally encapsulating the core. When the mounds are excavated, the core appears bluish or black due to a lack of oxygen and contains a lot of water, while the surrounding mantle is normally brown or yellowish-brown and dry. The core contains large quantities of un-decomposed organic matter while plant material on the sods of the surrounding mantle is decomposed.

A burial mound with the blue core described in the text (HBM).

The main burials are normally found within the core. When excavated more than 3000 years after interment, well-preserved oak log coffins have been uncovered. By this process, some of the most remarkable discoveries from prehistoric southern Scandinavia have been made, as corpses, costumes, food, weapons and other implements are extremely well preserved. The existence of the lower iron pan protects the soil below the mound against leaching and this buried soil profile, called a *palaeosol*, can provide valuable information on the state of farmland soils in the past.

A 3400 year old oak coffin from a burial mound in Egtved, Denmark. The soil conditions have allowed the coffin to survive the passage of time in a remarkable state of presentation. The tree used to make the coffin was felled in the year 1370 BC (HBM).

Soil mapping and cultural heritage

Soil maps are a valuable tool for explaining the location of past settlements. Matching the density of settlements to areas with good soil for farming is a tested technique. However, such soil might not necessary be what we consider today as the best soil. Communities with low agricultural technologies may have preferred sandy soil to loamy and clayey soil because of tillage problems. Mapping soil chemistry can be used for finding previous settlements, fields or industrial production places such as iron smelting. Sampling soil for phosphorus has been used to infer previous settlements while augering can be used to identify burial mounds. Techniques such as metal detecting and geo-magnetism are valuable tools for discovering treasures in the topsoil and former structures, now buried beneath the soil.

Auger sample showing material from a burial mound superimposing a soil from the Bronze Age (1300-1400 BC) (HBM).

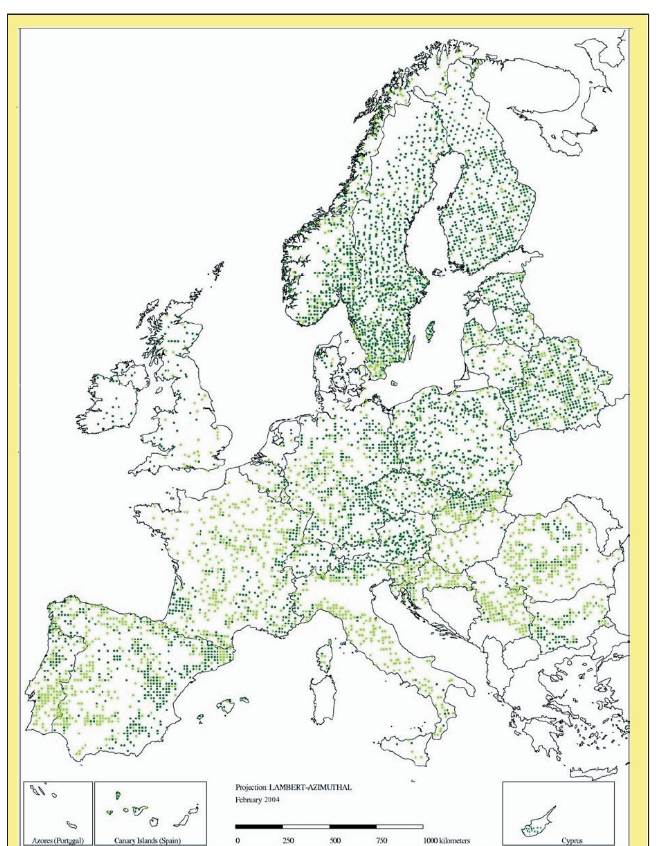
Forest soil

The soil component in forest ecosystems

Soil has a major ecological role in forest ecosystems, involving many organisms and individual chemical processes. Soil provides moisture, nutrients and physical support for plants and serves as a filter for toxic substances and a receptor for natural wastes. In forestry, soil is the resource, whereas trees are merely a crop. The forest cover and the associated forest floor provide a micro-climate and a spectrum of organisms different from those associated with most other soil types. Differences between agricultural and forest soils derive, in part, from the fact that often the most "desirable" soil has been selected for agricultural use and the remainder left for native vegetation such as forest. Fortunately, soil requirements for forest trees frequently differ from those for agricultural crops. Poor drainage, steep slopes, or the presence of large stones are examples of soil conditions that favour forestry over agricultural use.

The European forest soil condition survey

Public concern for the health of European forest ecosystems in the late 1970s and early 1980s resulted in an extensive forest soil condition monitoring programme set up by the European Commission and the International Co-operation Programme on the Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The first pan-European forest soil survey, carried out in the 1990s with the participation of thirty one countries, assessed the chemistry and properties of soil which determine a vulnerability to air pollution. Forest soils were sampled at the intersection points of a trans-national 16 km x 16 km grid (network of Level I plots – see figure below). Sampling and analyses were carried out by several laboratories across Europe.



Presently, the Forest Soil Condition Database contains information on 5289 forest plots covering 28 countries.

The European forest soil condition database

The results of the first large-scale forest soil survey were published in a report on the "Forest Soil Condition in Europe" in 1997, based on a database of 4,532 plots in 23 countries. The database was later extended up to 5,289 plots, representing 28 countries. For each plot, the database consists of general information, such as the soil classification name and chemical and physical data of organic and mineral soil layers. The mineral soil was sampled at two or three fixed depths between 0 and 20 cm and then analysed for a range of elements (e.g. pH, organic carbon, nitrogen and metals).

Evaluation of the European forest soil condition

The results of the survey reflect the spatial variability of the forest soil condition in Europe and show a correlation between the soil chemistry and atmospheric deposition of nitrogen, acidity and heavy metals:

- Higher nitrogen content in the organic layer of forest soils is observed in areas receiving high atmospheric deposition compared to remote areas in Europe. Nitrogen deposition, decreasing the carbon/nitrogen ratio of humus layers, will disturb organic matter and nutrient cycling.
- Results indicated a relationship between acid deposition and pH. However, for base saturation such a direct relationship could not be substantiated. This may be due to the fact that other factors, such as climate and soil type, strongly influence base saturation. Extremely acid topsoil conditions (i.e. having a mineral surface layer pH value below 3.0) were reported for a number of plots, located almost exclusively in the region receiving a very high atmospheric deposition. A common characteristic of these soil types is a low reserve of basic exchangeable cations, indicating a low buffering capacity against acidification.
- Atmospheric deposition has resulted in high levels of heavy metals in strongly industrialised areas. Concentrations of certain heavy metals, particularly lead and zinc, in humus layers and topsoils show regional gradients reflecting atmospheric deposition patterns. The majority of plots having an organic layer with high lead and zinc concentrations are found in the regions with the highest deposition load.

A tower to measure and monitor air pollution in a forest ecosystem. Instruments at different levels on the tower sample the air to build up a profile of pollution in the forest (EVR).

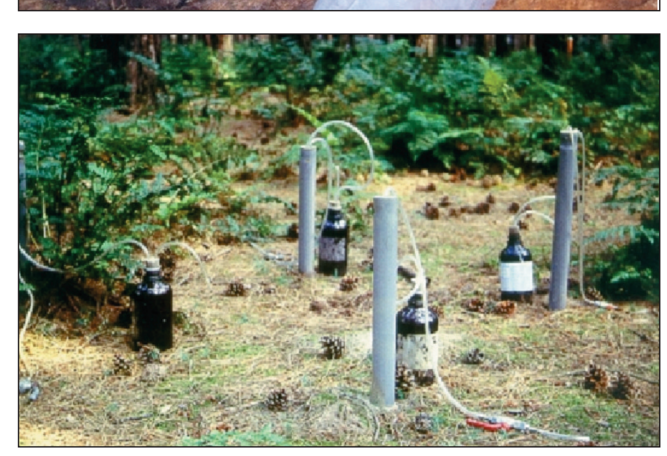
The chemical data allowed an assessment of the soil's capacity to perform its ecological functions within the forest ecosystem. The capacity to supply nutrients (e.g. nitrogen, phosphorus and basic cations), the sensitivity to acidification, and the capacity to immobilise heavy metals (e.g. zinc, lead and cadmium) are important indicators of forest soil quality in strongly industrialised regions.

The Forest Soil Condition Database offers numerous application possibilities, such as the investigation of the soil stress factors on tree condition, the improvement of critical load calculations, estimation of weathering rates and the extrapolation of soil data to sites where no information is available.

Future activities

The results of the large-scale forest soil condition survey may contribute in revealing the role of air pollution as an important stress factor for forest ecosystems. However, to assess soil changes induced by atmospheric deposition soil condition measurements should be repeated at regular time intervals. At the start of the forest soil Level I programme, plans were made to repeat the survey every ten years. Since the implementation of the Level II programme of ICP Forests in 1994, 770 intensive monitoring plots have been established in 29 European countries. In these plots, more parameters are assessed more frequently and with a higher intensity at a lower number of plots than in the Level I programme in order to recognise factors and processes affecting forest condition. Instead of using a systematic network covering the total forest area, plots are selected in a way that all important forest ecosystems are represented.

An experimental forest plot in northern Belgium (Brasschaat) where (above) pine trees (Pinus sylvestris) are growing on a deep ploughed Podzol (see profile below) (EVR).



Special instruments known as lysimeters have been positioned in the forest to collect data on the amount and the chemical composition of soil water at different soil depths (EVR).

Soil as a source of raw material

Soil is an important source of raw materials. Although the concept is quite clear for agriculture where it is the main raw material from which food is produced, soil provides raw materials such as clay, sands, minerals and peat which are used for many different industrial applications.

As is the case of "more traditional" raw material such as iron ore, oil and natural gas, soil is essentially a non-renewable resource with potentially rapid degradation rates and extremely slow formation and regeneration processes. The use of soil as a source of raw materials is obviously depleting the available soil resources and is considered as a non-sustainable type of soil use.

Peat as a fuel

Peat is the accumulated remains of plant materials formed under waterlogged conditions where organisms responsible for the decay of plant remains are suppressed. Peat accumulation takes place at various rates depending on water regime, temperature and topography but average rates are of the order of 20 - 60 cm per 1000 years.

Throughout history, peat has been exploited, primarily as a source of fuel, particularly in Ireland, Scotland, Denmark, Scandinavia, Poland, northern Germany and Russia. Peat was traditionally cut by hand into rectangular blocks from long trenches dug across the bog. The blocks would then be spread out to dry before being used to fuel open fires and stoves. The drying process involves turning the peat blocks in order to allow air to circulate around the sods and to dry the peat from its cut moisture of 90% by weight to around 35% by weight. In this process, more than 8 tonnes of water are evaporated per tonne of peat!

Traditional cutting of peat for fuel in Scotland. Peat cut by hand was a slow procedure that allowed the vegetation to regenerate over time (RJ).

With the advent of oil and natural gas as primary fuels sources over the last forty years, there has been a steady decline in the use of peat as a fuel in private houses. The generation of electricity in many countries still utilises peat burning power stations (a medium sized power station can consume up to 1 million tonnes of peat annually).

Research in Scotland has recently suggested that the burning of certain types of peat was responsible for releasing a highly toxic chemical into the environment. Unusual levels of a substance known as dioxin, an organochlorine, had been discovered in soil samples pre-dating the twentieth century. Researchers discovered that burning coastal peat, which had high levels of sea salt (sodium chloride), could give off dioxins and expose people to these toxins.

Soil in horticulture

During the last forty years, there has been an explosion in the use of peat for horticultural activities where it is used as a growing media, a soil improver or mulch by amateur gardeners and the professional horticulture industry.

A major use of peat is the horticulture industry and amateur gardeners who have found that the unique physical, chemical and biological properties of peat-based products give excellent results. Peat is an excellent mineral-soil improver or conditioner. Due to a unique cellular structure, peat has high water and air holding capacities such that it can retain and subsequently provide moisture and air to the roots of plants (EM).

Many commercial companies have introduced intensive methods of peat extraction resulting in the mining of peat rather than the traditional sustainable harvesting approach. Peat mining is considered a particularly controversial use of soil as it depletes large areas of wetlands that are rich in biodiversity and are particularly fragile natural habitats. These mechanized methods can destroy the environment responsible for the creation of the peat.

Nowadays, a number of peat-free alternatives are readily available on the market, including cocoa shells, coir (from coconut husks), bark products, manure, leaf mould and garden compost. A switch to alternatives will not only reduce the use of peat but also reduce the volume of waste going to landfill sites.

Soil in construction

The mineral and textural properties of soil have been a valued resource in construction for hundreds of years.

The compressibility, plasticity (the ability of a soil to be moulded) and cohesion (the capacity of soil grains to remain together) properties were the basis for building the earliest houses. Sun-dried mud bricks, often referred to as *adobe*, are the world's oldest manufactured building material. The Great Wall of China, constructed over 2,000 years ago, was build from dried mud bricks. In a similar manner, clay rich soils were used to make pottery and roof tiles.

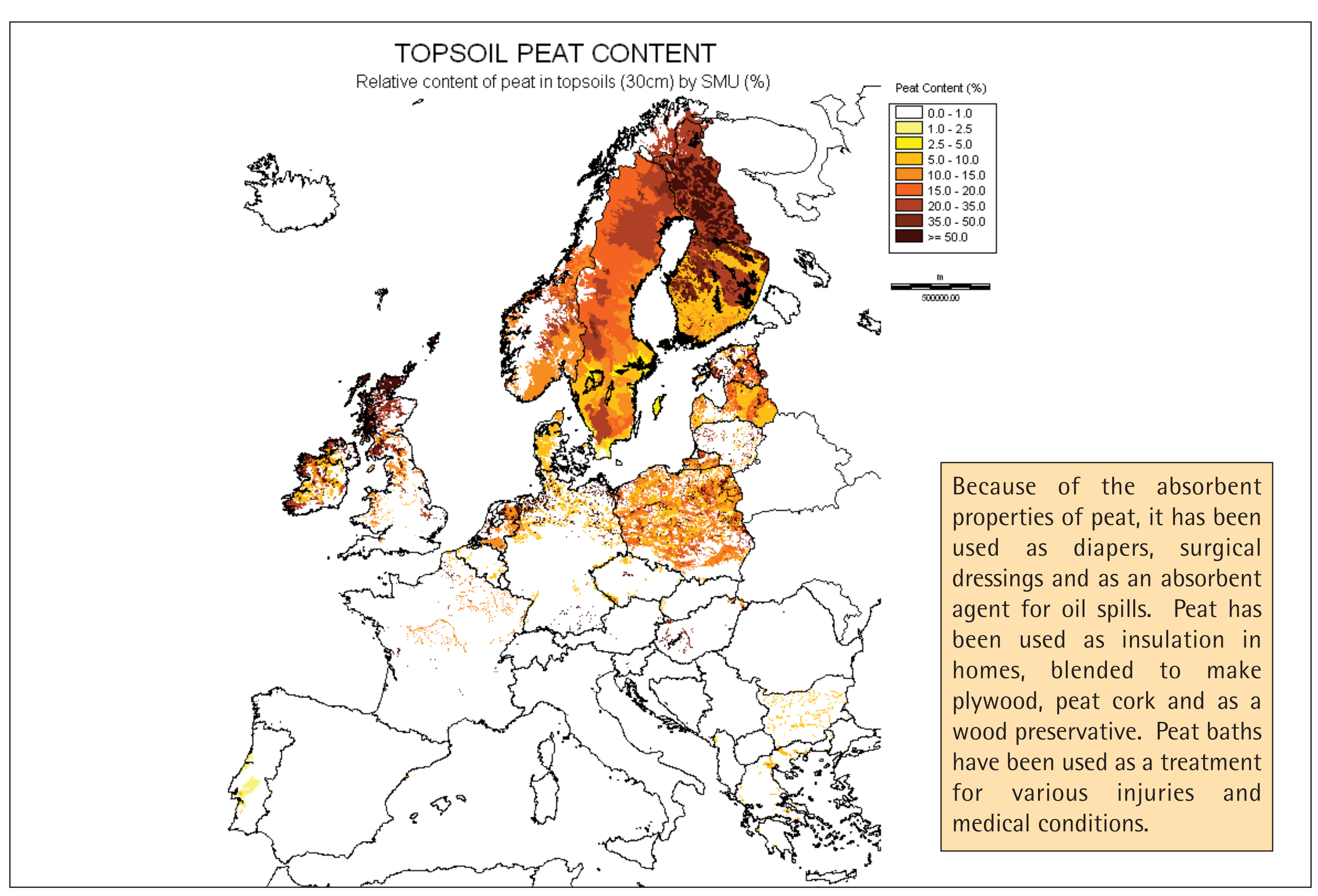
Even up to 200 years ago, the walls of many houses in Europe were built from woven wooden panels covered by "daub", a type of rendering made from a mixture of soil, cow dung and straw or grass.

The most important commercial sources of sand and gravel are river flood plains, river channels, and glacial deposits. Sand and gravel resources of Europe are large. However, because of their geographic distribution, environmental restrictions and quality requirements for some uses, sand and gravel extraction is uneconomic in some cases. Some countries mine offshore deposits of aggregates while increasingly, recycled construction materials are being used (RJ).

Sand and gravel are the most accessible basic raw material for the construction industry and are used as concrete aggregates, road base, mixed with bitumen for road surfaces, construction fill, snow and ice control (gritting), railroad ballast, roofing granules and water filtration systems.

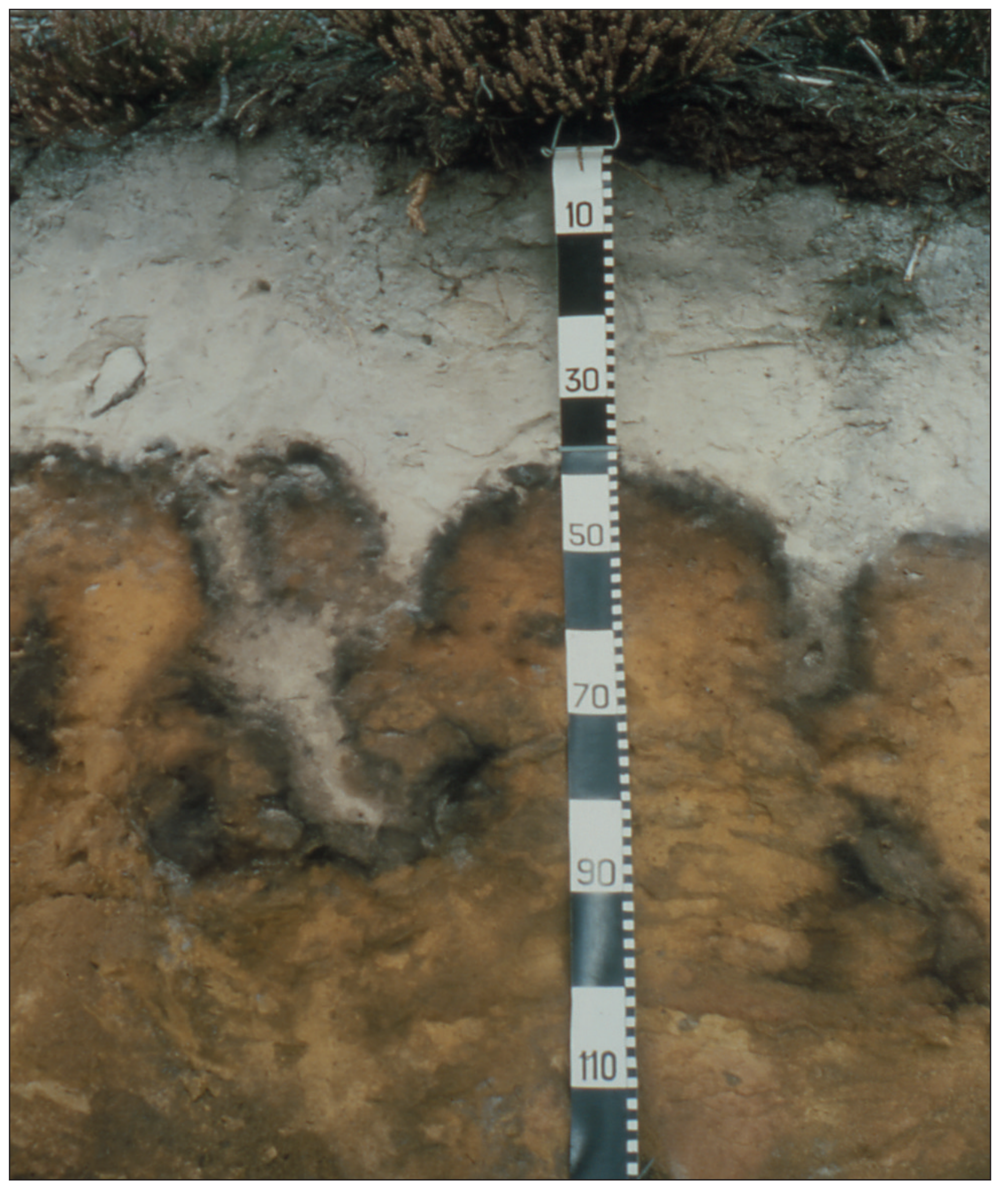
Clay minerals, an important constituent of soil, have an important commercial role. Kaolinite (otherwise known as "china clay") is widely used in the ceramics industry but is also used for paper coating and as a filler in paints. Vermiculite is well established as a growing medium, attic insulation and a useful packaging material. Being highly absorbent, it safely retains leaks from packed materials such as hazardous chemicals. As it is inorganic, it does not present any potential fire hazards. Because of its swelling properties, montmorillonite is utilised in some hair care products (e.g. shampoo) and as a liner for garden ponds.

Mud bricks used for construction in Mali (AB).



Because of the absorbent properties of peat, it has been used as diapers, surgical dressings and as an absorbent agent for oil spills. Peat has been used as insulation in homes, blended to make plywood, peat cork and as a wood preservative. Peat baths have been used as a treatment for various injuries and medical conditions.

The percentage content of peat in topsoil (0 – 30 cm) as mapped from the soil databases described later in the atlas (RH, RJ).



The two photographs on this page illustrate the influence of time on soil forming processes. Both pictures show Podzols. The above picture shows a typical mature Podzol soil with a well defined Spodic horizon. The term Spodic implies an accumulation of organic matter in the B horizon. This is the thinner dark zone that marks the boundary between the gray leached A horizon and the brown B horizon (HBM). The picture below shows a young soil developing in drifted sand. An organic rich layer, known as a mor, has developed on the surface of the soil and the podzolisation process has begun (HBM).

Soil classification

Introduction to soil classification

From the previous pages of this atlas, one can understand how different characteristics can develop within soil profiles or in different geographical areas. Apart from bare rock, glaciers and water, soil covers the Earth's surface as a continuum. The gradual changes of soil characteristics across the landscape make the study and comparison of different soil types difficult. To overcome this problem pedologists (scientists who study soils) have developed various ways to characterise soil bodies, identify, label and group them according to certain names and rules called nomenclature. This important task is known as soil classification, one of the advanced branches of basic and applied soil sciences.

Classification is the procedure to arrange soil into groups, categories or, as the word implies, classes, relevant to a specific purpose. For example, a fundamental soil scientist would consider soil classes matching the processes and mechanisms driving soil formation and geographical distribution; environmental scientists use soil types grouped according their ecological functioning, biological activity, buffering and water filtering capabilities; engineers need soil groups according to different building carrying capacities, roads construction, swelling and shrinking properties while agronomists wish to have information on crop suitability, responses to various chemicals and management practices. While classification schemes will group soil differently, classification also provides a common language to map soil types, exchange and compare knowledge about them.

Early soil classifications were based on individual characteristics such as the texture of soil (e.g. loam, clay or sand) or the parent material (e.g. alluvial soil, gravelly soil, etc.). During the late 1880s the Russian geologist Vasili Dokuchaev - now regarded as the father of soil science - was the first to suggest a more scientific classification based on the combination of soil characteristics in relation to their formation. This, so called genetic principle, remains the guide for most present day national soil classifications, distinguishing features resulting from soil-forming processes from those whose origin is geological.

Since the 1950s, most European countries have carried out an intensive soil survey to optimise the efficient use of their land resources. This success was based on well-established national soil classifications and standards. The foundation of the European Union brought about an increased interdependency for the countries supplies of food and agricultural products.

Vasili Dokuchaev (1846-1903) is widely regarded as the father of soil science. He was one of the first people to investigate the properties of soil in a systematic and scientific manner. He explained how soils reflect the environment in which they are formed. He introduced the concept of five soil forming factors (climate, organisms, topography, parent material, time) that are still accepted in modern soil science. Most of his new ideas were published in his classic book the "Russian Chernoziom". The picture was taken in the Docuchaev Museum in St. Petersburg where he worked (EM).

In order to create a common understanding of soil resources in different countries, a new soil classification system, named World Reference Base for Soil Resources (WRB), has been developed. The WRB, the soil classification scheme used for the soil maps in this atlas, has been adopted as the official soil classification system of the International Union of Soil Science (IUSS) and the accepted common scheme of soil databases of the European Union. The WRB is not meant to replace national soil classification systems but serves as a common denominator through which national soil classification systems can be compared and correlated.

The World Reference Base for soil resources

The WRB is a two-level system of soil classification with **30 Soil Reference Groups** (see below and Page 28) and a series of uniquely defined **qualifiers** for specific soil characteristics (see box on Page 28).

For describing and defining soils the WRB exploits the following nomenclature:

- soil characteristics comprise single observable or measured parameters;
- soil properties are a combination of characteristics indicating soil-forming processes;
- soil horizons represent three-dimensional bodies containing one or more soil properties;

Soil horizons and properties are used to describe and define soil classes if they are considered as being "diagnostic". This means reaching a certain degree of expression, as determined visually, by prominence, measurability, importance and relevance for soil formation, soil use and quantitative criteria. To be diagnostic, soil horizons also require a minimum thickness.

Soil Reference Groups

Twenty four soil reference groups represent the soil of Europe, 80% of the global range of soil types.

Organic soils, such as peat, are brought together in one soil reference group called **HISTOSOLS** while all *man-made soils*, which vary widely in properties and appearance but have in common that their properties are strongly affected by human intervention are aggregated to the **ANTHROSOLS** soil reference group.

Mineral soil whose formation is conditioned by the particular properties of their *parent material* are sub-divided in to the **ANDOSOLS** of volcanic regions, the sandy **ARENOSOLS** of desert areas, beach ridges, inland dunes or areas with highly weathered sandstone and the swelling / shrinking heavy clayey **VERTISOLS** of back-swamps, river basins, lake bottoms and other areas with a high clay content.

Mineral soils whose formation was influenced by their topographic setting (for example, soils associated with recurrent floods or on steep terrain) range from the **FLUVISOLS**, which show stratification or other evidence of recent *alluvial* sedimentation, non-stratified **GLEYSOLS** in *waterlogged areas* and shallow **LEPTOSOLS** over hard rock or highly calcareous material, to the deeper **REGOSOLS**, which occur in unconsolidated materials that have a weak profile development because of low soil temperatures, prolonged dryness or erosion.

Soils that are only moderately developed on account of their young pedogenetic age or because of *rejuvenation* of the soil material are referred to as **CAMBISOLS.**

The wet tropical and subtropical regions where high soil temperatures and ample moisture promotes rock weathering, rapid decay of soil organic matter, a long history of dissolution and transport of weathering products has produced five types of deep and mature soil types. **PLINTHOSOLS** are marked by the presence of a mixture of clay and quartz ('plinthite') that hardens irreversibly upon exposure to the open air while deeply weathered **FERRALSOLS** have a very low cation exchange capacity and are virtually devoid of weatherable minerals. **ALISOLS** have high cation exchange capacity and much exchangeable aluminium, **NITISOLS** have deep profiles in relatively rich parent material, **ACRISOLS** develop on acid parent rock with a clay accumulation horizon, low cation exchange capacity and low base saturation while **LIXISOLS** possess a low cation exchange capacity but high base saturation percentage.

Soil in arid and semi-arid regions are differentiated to either **SOLONCHAKS** with a high content of soluble salts, **SOLONETZ** with a high percentage of adsorbed sodium ions, **GYPSISOLS** with a horizon of secondary gypsum enrichment, **DURISOLS** with a layer or nodules of soil material that is cemented by silica and **CALCISOLS** with secondary carbonate enrichment.

Soils that occur in the steppe zone between dry and humid temperate climates where vegetation consists of ephemeral grasses and dry forest classify to three Reference Soil Groups. **CHERNOZEMS** with deep, very dark surface soil and carbonate enrichment in the subsoil, **KASTANOZEMS** with less deep, brownish surface soils and carbonate and/or gypsum accumulation at some depth and the **PHAEOZEMS**, the dusky red soils of prairie regions with high base saturation but no visible signs of secondary carbonate accumulation.

The brownish and greyish soils of humid temperate regions show evidence of clay or organic matter redistribution. Eluviation and illuviation of metal-humus complexes produce the greyish (bleaching) and brown to black (coating) colours of soils. Five soil reference groups include the acid **PODZOLS** with a bleached eluviation horizon over an accumulation horizon of organic matter with aluminium and/or iron, **PLANOSOLS** with a bleached topsoil over dense, slowly permeable subsoil, base-poor **ALBELUVISOLS** with a bleached eluviation horizon tonguing into a clay-enriched subsurface horizon, base-rich **LUVISOLS** with a distinct clay accumulation horizon and **UMBRISOLS** with a thick, dark, acid surface horizon that is rich in organic matter.

Soil of permafrost regions that shows signs of 'cryoturbation' (i.e. disturbance by freeze-thaw sequences and ice segregation) are assembled in one soil reference group, the **CRYOSOLS.**

How is the WRB classification system used?

The following steps have to be undertaken to classify a soil:

- Identification of soil characteristics through observation in the field, supported by laboratory analyses;
- Determination of the presence and type of horizons (see Page 27);
- Identification of specific vertical successions of horizons on the basis of which the soil , considered, is defined;
- Application of the key to the WRB Reference Groups to determine the Soil Group in terms of a specific combination of horizons. A simplified key is given **below.**

Start Here: Does the soil profile have:

Organic matter> 40 cm deep	Yes	**HISTOSOLS**
No, then does it have a:		
Cryic horizon	Yes	**CRYOSOLS**
No, then does it have:		
Human modifications	Yes	**ANTHROSOLS**
And so on until you can answer yes.		
Depth < 25 cm	Yes	**LEPTOSOLS**
> 35% clay vertic horizon	Yes	**VERTISOLS**
Fluvic materials	Yes	**FLUVISOLS**
Salic horizon	Yes	**SOLONCHAKS**
Gleyic properties	Yes	**GLEYSOLS**
Andic or vitric horizon	Yes	**ANDOSOLS**
Spodic horizon	Yes	**PODZOLS**
Natric horizon	Yes	**SOLONETZ**
Abrupt textural change	Yes	**PLANOSOLS**
Chernic horizon	Yes	**CHERNOZEMS**
Brownish mollic horizon and secondary CaCO3	Yes	**KASTANOZEMS**
Mollic horizon	Yes	**PHAEOZEMS**
Gypsic horizon	Yes	**GYPSISOLS**
Calcic horizon	Yes	**CALCISOLS**
Argic horizon and albeluvic tonguing	Yes	**ALBELUVISOLS**
Argic horizon with CECc < 24, BS < 50%	Yes	**ACRISOLS**
Argic horizon with CECc > 24, BS > 50%	Yes	**LUVISOLS**
Umbric horizon	Yes	**UMBRISOLS**
Cambic horizon	Yes	**CAMBISOLS**
Coarse texture > 100 cm	Yes	**ARENOSOLS**
Other soils	?	**REGOSOLS**

Soil Classification

Qualifiers of the Reference Soil Groups

Acroxic: having, within 100 cm from the soil surface, less than 2 cmol(+) per kg of exchangeable bases plus 1 M KCl exchangeable Al^{3+} in the fine earth fraction of one or more horizons with a combined thickness of 30 cm or more (in Andosols only).

Albic: having, within 100 cm from the soil surface, an albic horizon.

Andic: having, within 100 cm from the soil surface an andic horizon.

Arenic: having throughout the upper 50 cm soil layer a texture of loamy fine sand or coarser.

Aridic: having aridic properties without a takyric or yermic horizon.

Calcaric: calcareous at least between 20 and 50 cm from the soil surface.

Calcic: having, between 50 and 100 cm from the soil surface a calcic horizon or concentrations of secondary carbonates.

Carbic: having a cemented spodic horizon which does not contain sufficient amorphous iron to turn redder on ignition (in Podzols only).

Chernic: having a chernic horizon (in Chernozems only).

Chromic: having a subsurface horizon of which the major part has a Munsell hue of 7.5 YR and a chroma (moist) greater than 4 or a hue (moist) redder than 7.5 YR.

Dystric: having in at least some part between 20 and 100 cm from the soil surface, or in a layer directly above a lithic contact in Leptosols, a base saturation (in 1M ammonium acetate at pH 7.0) of less than 50 percent.

Eutric: having in at least some part between 20 and 100 cm from the soil surface, or in a layer directly above a lithic contact in Leptosols, a base saturation (in 1M ammonium acetate at pH 7.0) of more than 50 percent.

Endoeutric – Eutric: having a base saturation (in 1M ammonium acetate at pH 7.0) of 50 % or more in all parts between 50 and 100 cm from the soil surface.

Ferric: having, within 100 cm from the soil surface, a ferric horizon.

Fluvic: having, within 100 cm from the soil surface, fluvic soil material.

Gelic: having within 200 cm from the soil surface, permafrost.

Gleyic: having within 100 cm from the soil surface, gleyic properties.

Greyic: having uncoated silt and sand grains on structural ped faces in a mollic horizon (in Phaeozems only).

Haplic: having the typical expression of the Soil Reference Group in the sense that there is no further meaningful characterization.

Histic: having, within 100 cm from the soil surface, a histic horizon.

Humic: having, over a depth of 100 cm from the soil surface, more than 1 % organic carbon (by weight) in the fine earth fraction to a depth of 50 cm.

Lamellic: having within 100 cm from the soil surface, clay illuviation lamellae with a combined thickness of 15 cm or more.

Leptic: having continuous hard rock between 25 and 100 cm from the soil surface.

Luvic: having an argic horizon, which has a cation exchange capacity equal or greater than 24 cmo(+) per kg of clay (in ammonium acetate at pH 7.0) throughout and a base saturation of 50 % or more throughout the horizon to a depth of 100 cm from the soil surface.

Mollic: having a mollic horizon.

Placic: having within 100 cm from the soil surface a sub horizon of the spodic horizon which is 1 cm or more thick and which is continuously cemented by a combination of organic matter and aluminium, with or without iron (in Podzols only).

Rendzic: having a mollic horizon, which is between 10 and 25 cm thick and contains or immediately overlies calcaric soil material having more than 40 % calcium carbonate equivalent (in Leptosols only).

Rhodic: having a subsurface horizon with a Munsell hue of 5YR or redder in all parts, a moist colour value of less than 5.5 and a dry colour value no more than one unit higher than the moist value.

Rustic: having a cemented spodic horizon which has enough amorphous iron to turn redder on ignition, which underlies an albic horizon, and lacks a sub horizon which is 2.5 cm or more thick and which is continuously cemented by a combination of organic matter and aluminium, with or without iron (in Podzols only).

Skeletic: having between 40 and 90 percent (by weight) gravel or other coarse fragments to a depth of 100 cm from the soil surface.

Episkeletic: having between 40 and 90 percent (by weight) gravel or other coarse fragments between 20 and 100 cm from the soil surface.

Stagnic: having stagnic properties within 50 cm from the soil surface.

Terric: having a terric horizon, which is 50 cm thick in Anthrosols or more than 30 cm thick in other soils.

Thionic: having, within 100 cm from the soil surface, a sulfuric horizon or sulfidic soil material.

Umbric: having an umbric horizon.

Vermic: having in the upper 100 cm of the soil or down to rock or a petrocalcic, petrogypsic or petroplinthic horizon whichever is shallower, 50 percent or more (by volume) wormholes, worm casts and/or animal burrows.

Vertic: having, within 100 cm from the soil surface a vertic horizon or vertic properties.

Vitric: having, within 100 cm from the soil surface a vitric horizon and having no andic horizon overlying the vitric horizon.

While the ***above box*** lists the **qualifiers** of the **reference soil groups**, the ***box below*** explains the **diagnostic horizons, properties and materials** that are used for the above definitions. Some of the terminology used on this page may seem very complicated but it reflects the detail required to assign the continuum that is soil to one group or another. What is also evident is that many of these criteria can only be determined through laboratory analysis. Thus, the correct classification of a soil involves an understanding of the position of the soil in the landscape, observations of the soil profile carried out in the field and supporting laboratory measurements.

Surface horizons and subsurface horizons at shallow depth

anthropogenic: surface and subsurface horizons resulting from long-continued human processes, notably deep working, intensive fertilisation, addition of earthy materials, irrigation or wet cultivation

chernic: deep, well-structured, blackish surface horizon with a high base saturation, high organic matter content, strong biological activity and well-developed, usually granular, structure. Its carbon content is intermediate between a mollic horizon and a histic horizon

folic: surface horizon, or subsurface horizon at shallow depth, consisting of well-aerated organic soil material

fulvic: thick, black surface horizon having a low bulk density and high organic carbon content conditioned by short -range -order minerals (usually allophane) and/or organo-aluminium complexes

histic: (peaty) surface horizon, or subsurface horizon occurring at shallow depth, consisting of organic soil material

melanic: thick, black surface horizon conditioned by short-range-order minerals (usually allophane) and/or organo-aluminium complexes. Similar to the fulvic horizon except for a `melanic index' of 1.70 or less throughout

mollic: well-structured, dark surface horizon with high base saturation and moderate to high organic carbon content

ochric: surface horizon without stratification, which is either light coloured, or thin, or has a low organic carbon content, or is massive and (very) hard when dry

takyric: finely textured surface horizon consisting of a dense surface crust and a platy lower part; formed under arid conditions in periodically flooded soils

umbric: well-structured, dark surface horizon with low base saturation and moderate to high organic matter content

vitric: surface or subsurface horizon rich in volcanic glass and other primary minerals associated with volcanic ejecta

yermic: surface horizon of rock fragments (`desert pavement') usually, but not always, embedded in a vesicular crust and covered by a thin aeolian sand or loess layer

Subsurface horizons

albic: bleached eluviation horizon with the colour of uncoated soil material, usually overlying an illuviation horizon

andic: horizon evolved during weathering of mainly pyroclastic deposits; mineral assemblage dominated by short-range-order minerals such as allophane

argic: subsurface horizon having distinctly more clay than the overlying horizon as a result of illuvial accumulation of clay and/or pedogenetic formation of clay in the subsoil and/or destruction or selective erosion of clay in the surface soil

cambic: genetically young subsurface horizon showing evidence of alteration relative to underlying horizons: modified colour, removal of carbonates or presence of soil structure

cryic: perennially frozen horizon in mineral or organic soil materials

calcic: horizon with distinct calcium carbonate enrichment

duric: subsurface horizon with weakly cemented to indurated nodules cemented by silica (SiO2) known as `durinodes'

ferralic: strongly weathered horizon in which the clay fraction is dominated by low activity clays and the sand fraction by resistant materials such as iron-, aluminium-, manganese- and titanium oxides

ferric: subsurface horizon in which segregation of iron has taken place to the extent that large mottles or concretions have formed in a matrix that is largely depleted of iron

fragic: dense, non-cemented subsurface horizon that can only be penetrated by roots and water along natural cracks and streaks

gypsic: horizon with distinct calcium sulphate enrichment

natric: subsurface horizon with more clay than any overlying horizon(s) and high exchangeable sodium percentage; usually dense, with columnar or prismatic structure

nitic: clay-rich subsurface horizon with a moderate to strong polyhedric or nutty structure with shiny ped faces

petrocalcic: continuous, cemented or indurated calcic horizon

petroduric: continuous subsurface horizon cemented mainly by secondary silica (SiO_2), also known as a `duripan'

petrogypsic: cemented horizon containing secondary accumulations of gypsum ($CaSO_4.2H_2O$)

petroplinthic: horizon continuous layer indurated by iron compounds and without more than traces of organic matter

plinthic: subsurface horizon consisting of an iron-rich, humus -poor mixture of kaolinitic clay with quartz and other constituents, and which changes irreversibly to a hardpan or to irregular aggregates on exposure to repeated wetting and drying with free access of oxygen

salic: surface or shallow subsurface horizon containing 1 % of readily soluble salts or more

spodic: dark coloured subsurface horizon with illuvial amorphous substances composed of organic matter and aluminium, with or without iron

sulfuric: extremely acid subsurface horizon in which sulphuric acid has formed through oxidation of sulphides

vertic: subsurface horizon rich in expanding clays and having polished and grooved ped surfaces (`slickensides'), or wedge-shaped, or parallelepiped structural aggregates formed upon repeated swelling and shrinking

Descriptive summary of diagnostic properties

abrupt textural change: very sharp increase in clay content within a limited vertical distance

albeluvic tonguing: iron-depleted material penetrating into an argic horizon along ped surfaces

alic properties: very acid soil material with a high level of exchangeable aluminium

aridic properties: refer to soil material low in organic matter, with evidence of aeolian activity, light in colour and (virtually) base-saturated

continuous hard rock: material which is sufficiently coherent and hard when moist to make digging with a spade impracticable

ferralic properties: indicate that the (mineral) soil material has a `low' cation exchange capacity or would have qualified for a ferralic horizon if it had been less coarsely textured

geric properties: mark soil material of very low effective cation exchange capacity or even acting as anion exchanger

gleyic properties: visible evidence of prolonged waterlogging by shallow groundwater

permafrost: indicates that the soil temperature is perennially at or below $0^{O}C$ for at least two consecutive years

secondary carbonates: significant quantities of translocated lime, soft enough to be readily cut with a finger nail, precipitated from the soil solution rather than being inherited from the soil parent material

stagnic properties: visible evidence of prolonged waterlogging by a perched water table

strongly humic properties: indicative of a high content of organic carbon in the upper metre of the soil

Descriptive summary of diagnostic materials

anthropogenic: unconsolidated mineral or organic material produced largely by human activities and not significantly altered by pedogenetic processes

calcaric: soil material, which contains more than 2 percent calcium carbonate equivalent and shows strong effervescence with 10 percent HCl in most of the fine earth

fluvic: fluviatile, marine and lacustrine sediments, which show stratification in at least 25 percent of the soil volume over a specified depth and/or have an organic carbon content decreasing irregularly with depth

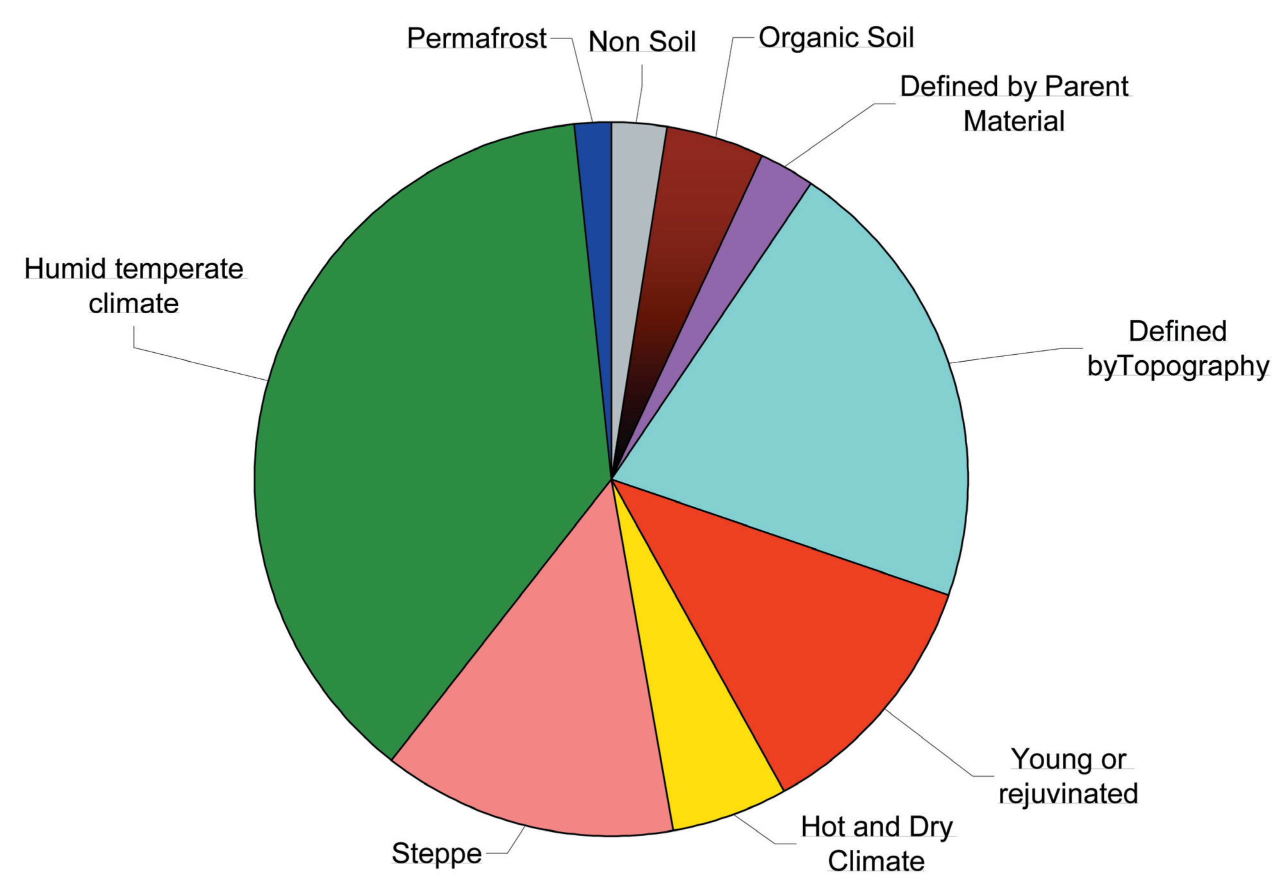
gypsiric: mineral material, which contains 5 percent or more gypsum (by volume)

organic: organic debris, which accumulates at the surface and in which the mineral component does not significantly influence soil properties

sulfidic: waterlogged deposit containing sulphur, mostly sulphides, and not more than moderate amounts of calcium carbonate

tephric: non or only slightly weathered products of volcanic eruptions, with or without admixtures of material from other sources

Soil Classification: Grouping soil types together



Distribution of soil types in Europe and Russia (to the Ural Mountains) according to their key characteristic. This figure clearly shows that Europe is dominated by soil reflecting the generally humid-temperate climate of the continent (AJ).

This picture shows the variability of different soil types across a river valley and illustrates the need to accurately characterise and classify soils into distinct classes (EM).

An example of an exercise to classify a soil according to WRB methodology.

The soil shown in the above picture satisfies the Chernozem criteria if it posses the following characteristics (EM):

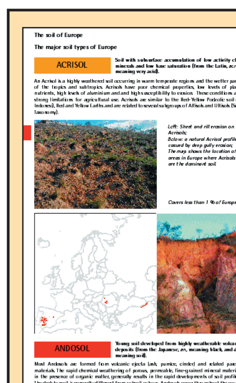
1. *having a mollic horizon with a moist chroma of 2 or less if the texture is finer than sandy loam, or less than 3.5 if the texture is sandy loam or coarser, both to a depth of at least 20 cm, or a mollic horizon which has these chromas directly below a plough layer; and having*
2. *concentrations of secondary carbonates starting within 200 cm from the soil surface; and*
3. *no petrocalcic horizon between 25 and 100 cm from the soil surface; and*
4. *no secondary gypsum; and*
5. *no uncoated silt and sand grains on structural ped surfaces.*

From various field and laboratory examinations the soil does indeed turn out to be a Chernozem. The next step is to identify the qualifiers. The table below lists the possible qualifiers for Chernozems.

Chernic	having a chernic horizon
Vertic	having a vertic horizon within 100 cm from the soil surface.
Gleyic	having gleyic properties within 100 cm from the soil surface.
Luvic	having an argic horizon which has a cation exchange capacity equal to or more than 24 cmolc kg-1 clay throughout, and a base saturation by 1 M NH4OAc) of 50 percent or more throughout the horizon to a depth of 100 cm from the soil surface.
Glossic	showing tonguing of the mollic horizon into an underlying B horizon or into the saprolite.
Calcic	having, between 50 and 100 cm from the soil surface, a calcic horizon or concentrations of secondary carbonates
Siltic	having, within 100 cm from the soil surface, a layer more than 30 cm thick and containing 40 percent or more silt
Vermic	having, in the upper 100 cm of the soil 50 percent or more (by volume) wormholes, worm casts, and/or filled animal burrows.
Haplic	If no other qualifier applies

From our analysis, we see that for this soil the Calcic, Siltic and Vermic qualifiers apply.

Therefore, following the rules set by WRB, the full name of the soil is **Silti-Calcic Chernozem (Vermic)**



To learn more about the main WRB Reference Group soils that occur in Europe. please refer to the following pages. The key characteristics of each soil is explained with supporting pictures and a map showing the locations where the soil is dominant.

The major soil types of Europe

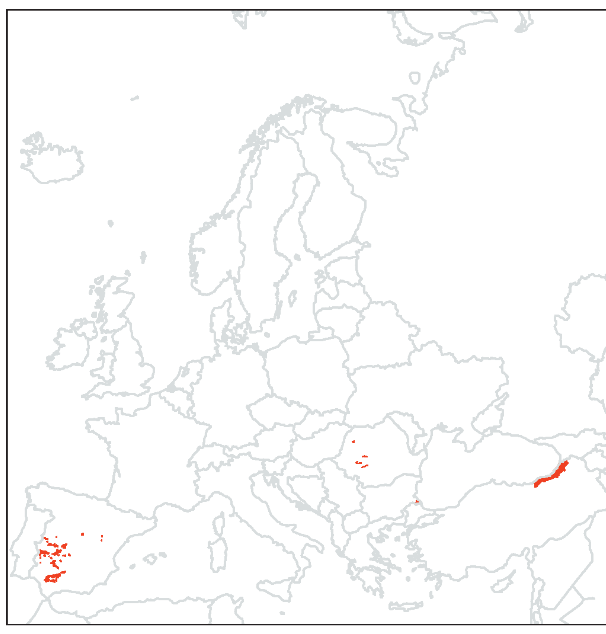
ACRISOLS

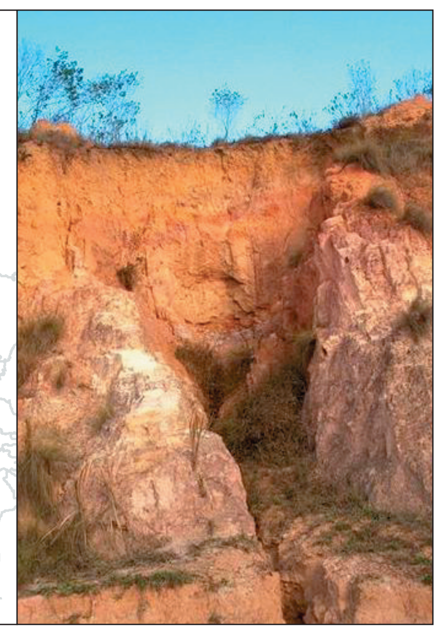
Soil with subsurface accumulation of low activity clay minerals and low base saturation (from the Latin, *acris*, meaning very acid).

An Acrisol is a highly weathered soil occurring in warm temperate regions and the wetter parts of the tropics and subtropics. Acrisols have poor chemical properties, low levels of plant nutrients, high levels of aluminium and high susceptibility to erosion. These conditions are strong limitations for agricultural use. Acrisols are similar to the Red-Yellow Podzolic soil of Indonesia, Red and Yellow Earths and are related to several subgroups of Alfisols and Ultisols (Soil Taxonomy).

Left: *Sheet and rill erosion on Acrisols;*
Below: *a natural Acrisol profile exposed by deep gully erosion;*
The ***map*** *shows the location of areas in Europe where Acrisols are the dominant soil type.*

Cover less than 1 % of Europe.





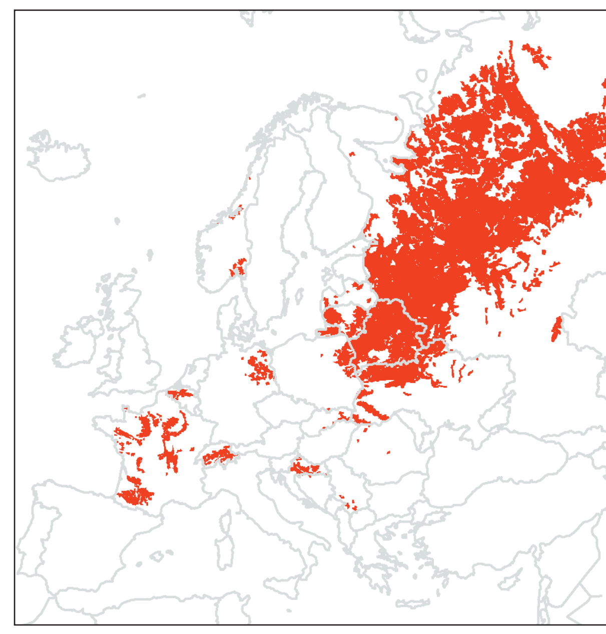
ALBELUVISOLS

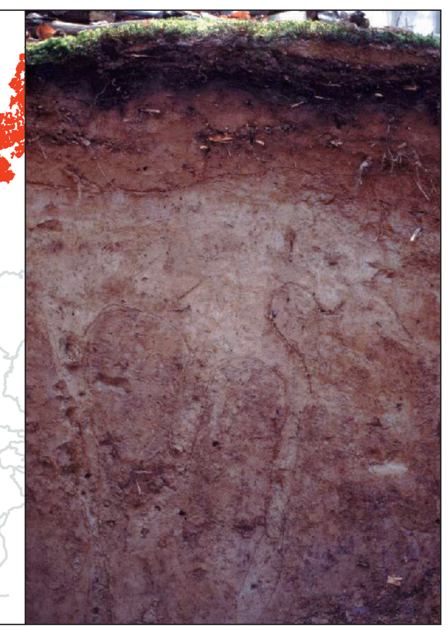
Acid soil with a bleached horizon penetrating a clay accumulation horizon (from the Latin, *albus*, meaning white and *eluere*, meaning to wash out).

Albeluvisols have an accumulation of clay in the subsoil with an irregular or broken upper boundary and deep penetrations or 'tonguing' of bleached soil material into the illuviation horizon. The typical "albeluvic tongues" are generally the result of freeze-thaw processes in periglacial conditions and often show a polygonal network in horizontal cuts. Albeluvisols occur mainly in the moist and cool temperate regions. Also known as Podzoluvisols (FAO), Ortho-podzolic soil (Russia) and several suborders of the Alfisols (Soil Taxonomy).

Left: *Albeluvisols develop mostly under forest vegetation;*
Below: *Albeluvic tongues are clearly visible penetrating the bleached illuvial horizon; The* ***map*** *shows the location of areas in Europe where Albeluvisols are the dominant soil type.*

Cover 15 % of Europe, the most common soil.





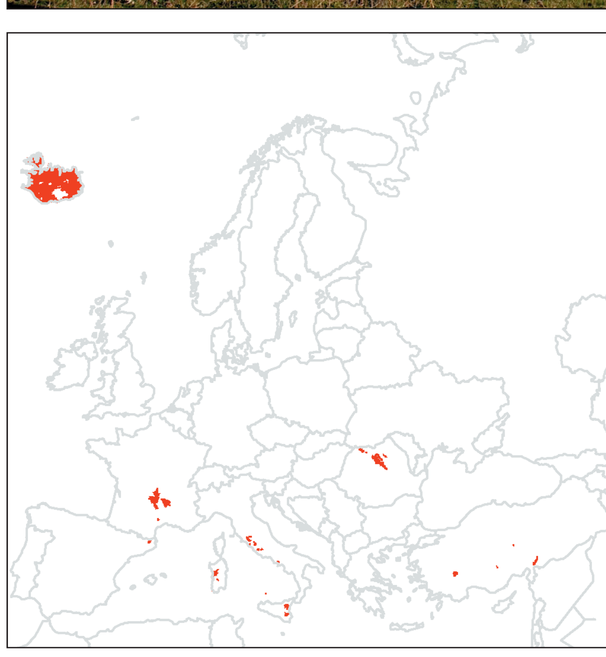
ANDOSOLS

Young soil developed from highly weatherable volcanic deposits (from the Japanese, *an*, meaning black, and *do*, meaning soil).

Most Andosols are formed from volcanic ejecta (ash, pumice, cinder) and related parent materials. The rapid chemical weathering of porous, permeable, fine-grained mineral material, in the presence of organic matter, generally results in the rapid development of soil profiles. The dark topsoil is generally different in colour from subsoil. Andosols occur throughout the world where volcanic activity is common. Other international names are Andisols (Soil Taxonomy), Vitrisols (France) and volcanic ash soil.

Left: *Fertile pasture land developed on old volcanic ash deposits – note the cinder cones in the distance;*
Below: *An Andosol develops in unconsolidated volcanic deposits – note the contrast in colour of the horizon; The* ***map*** *shows the location of areas in Europe where Andosols are the dominant soil type.*

Cover around 1 % of Europe.



ANTHROSOLS

Soil formed or modified by human activity that caused profound changes in soil properties (from the Greek, *anthropos*, meaning man).

An Anthrosol is a soil that was formed or significantly modified through human activities ranging from long-term deep cultivation (e.g. terraces), substantial additions of mineral and organic fertilizers, continuous application of earth (e.g. sods, shells), irrigation and substantial additions of sediment to wet cultivation involving *puddling* of the surface soil. The morphological and chemical characteristics of this soil vary depending on the specific human activity. Anthrosols are also known as Plaggen soil, Paddy soil, Oasis soil and Terra Preta do Indio.

Left: *"Plaggen" fertilization over time has resulted in a raised land surface. Farm houses often lie deeper than their surroundings. (RL);* ***Below:*** *Thick, black Anthrosol in Belgium, overlying remnants of a Podzol developed by long-term fertilization of sods or "Plaggen" mixed with animal manure. Spade marks are clearly visible at the boundary between the Anthrosol and the buried Podzol; The* ***map*** *shows the location of areas in Europe where Anthrosols are the dominant soil type.*

On a continental scale, it is the dominant soil in less than 0.1 % of Europe but locally can be very important.

The major soil types of Europe

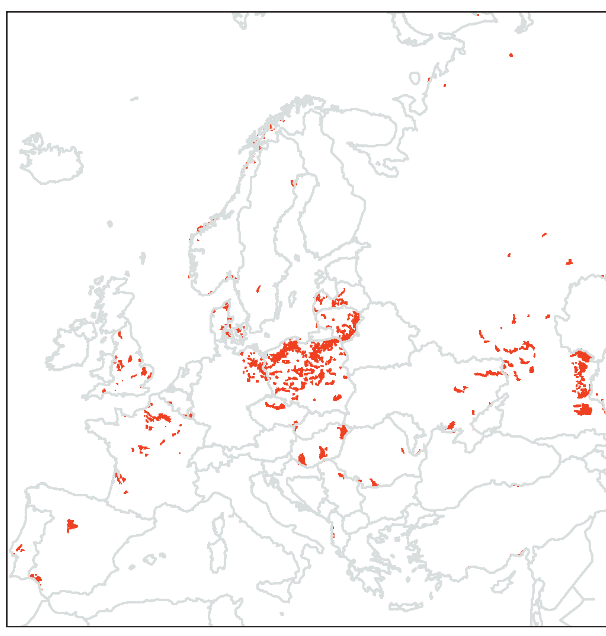
ARENOSOLS

Easily erodable sandy soil with slow weathering rate, low water and nutrient holding capacity and low base saturation (from the Latin, *arena*, meaning sand).

Arenosols have a coarse texture to a depth of one metre or to a hard layer. Soil formation is limited by low weathering rate and frequent erosion of the surface. If vegetation has not developed, shifting sands dominate. Accumulation of organic matter in the top horizon and/or lamellae of clay, and/or humus and iron complexes, mark periods of stability. Arenosols are amongst the most extensive soil types in the world.

__Left:__ the surface of Arenosols are often unstable in the absence of continuous vegetation cover; __Below:__ stabilized Arenosol with organic matter accumulation at the surface and lamellae in the subsurface; The __map__ shows the location of areas in Europe where Arenosols are the dominant soil type.

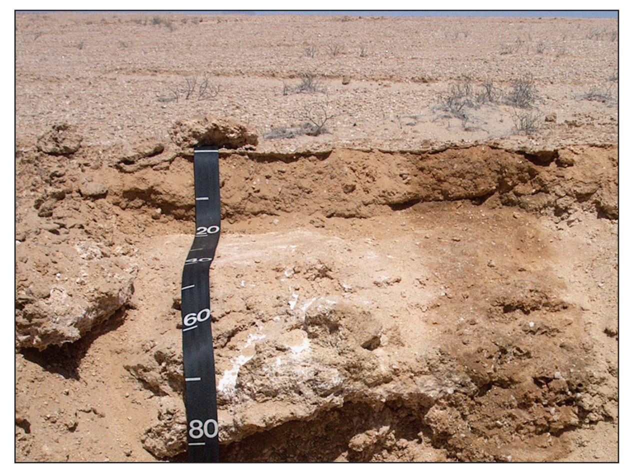
Cover 1 % of Europe.



CALCISOLS

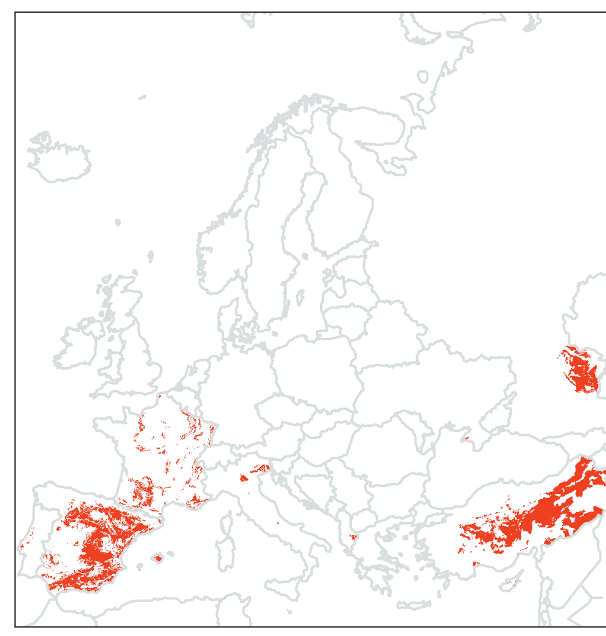
Soil with significant accumulation of secondary calcium carbonates, generally developed in dry areas (from the Latin, *calcarius*, meaning calcareous or lime-rich).

Calcisols have substantial movement and accumulation of calcium-carbonate within the soil profile. The precipitation may occur as *pseudomycelium* (root channels filled with fine calcite), nodules or even in continuous layers of soft or hard lime (*calcrete*). Calcisols are common on calcareous parent material in regions with distinct dry seasons, as well as in dry areas where carbonate-rich groundwater comes near the surface. Formerly Calcisols were internationally known as Desert soil and Takyrs.



__Left:__ a typical Calcisol landscape showing a hard calcrete layer; __Below:__ the deposition and accumulation of calcium carbonate ($CaCO_3$) may form a continuous hard pan layer; The __map__ shows the location of areas in Europe where Calcisols are the dominant soil type.

Cover 5 % of Europe.



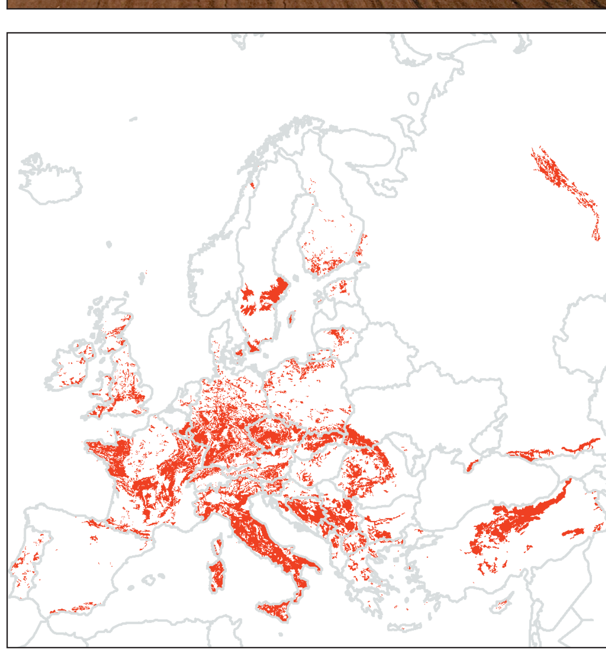
CAMBISOLS

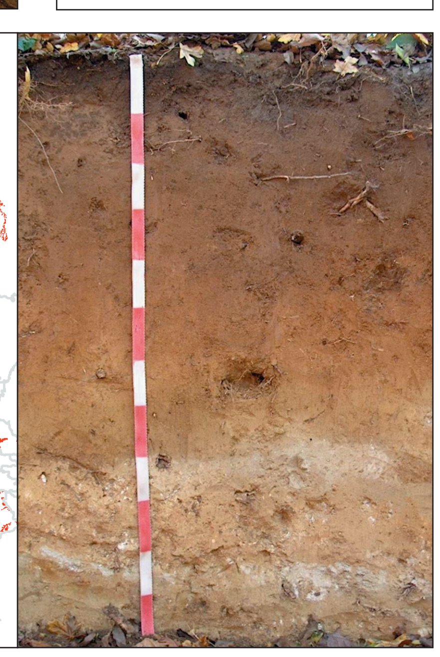
Soil that is only moderately developed on account of limited age or rejuvenation of the soil material (from the Latin *cambiare* meaning to change).

A Cambisol is a young soil. Pedogenic processes are evident from colour development and/or structure formation below the surface horizon. Cambisols occur in a wide variety of environments around the world and under all many kinds of vegetation. Commonly referred to as brown soil, Braunerde (Germany), Sols bruns (France) or Brunizems (Russia). The USDA Soil Taxonomy classifies Cambisols as Inceptisols.

__Left:__ Cambisols are common in Europe and can be very productive agriculturally, especially in loess areas; __Below:__ Pedogenic processes are evident in colour development or structure formation below the surface horizon; The __map__ shows the location of areas in Europe where Cambisols are the dominant soil type.

Cover 12 % of Europe.





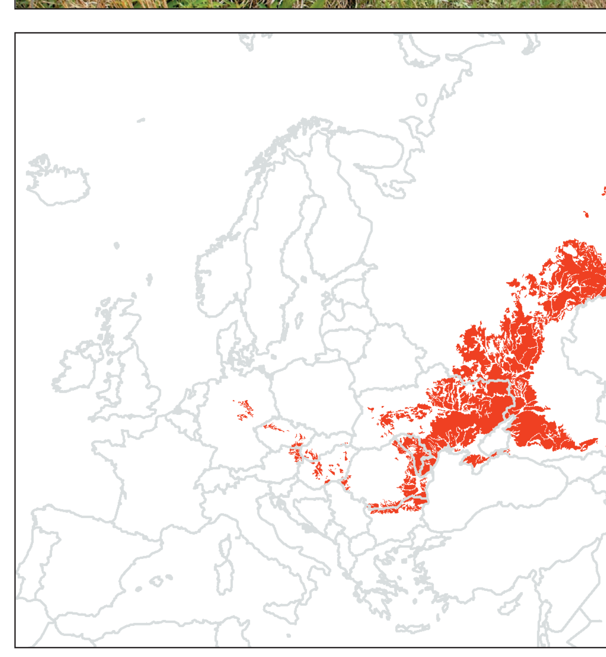
CHERNOZEMS

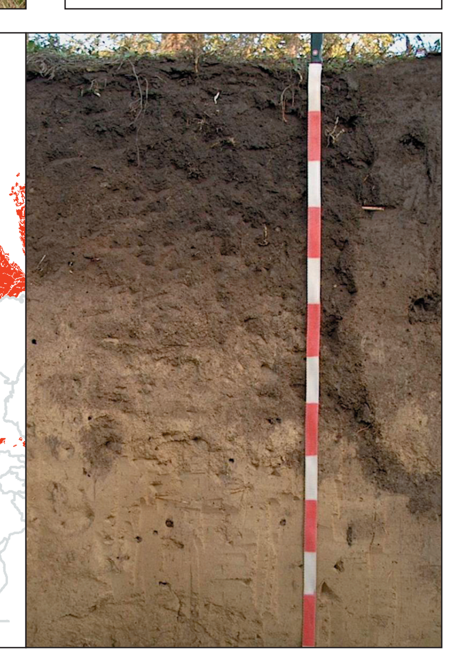
Soil with a deep, dark surface horizon that is rich in organic matter and secondary calcium carbonate concentrations in the deeper horizons (from the Russian for *chern*, black, and *zemlja*, earth).

Soil having a very dark brown or blackish surface horizon with a significant accumulation of organic matter, a high pH and having calcium carbonate deposits within 50 cm of the lower limit of the humus rich horizon. Chernozems show high biological activity and are typically found in the long-grass steppe regions of the world, especially in Eastern Europe, Ukraine, Russia, Canada and the USA. Chernozems are amongst the most productive soil types in the world.

__Left:__ The main source of the high organic content of Chernozems is the annual decay of grass; __Below:__ the dark surface soil material is generally mixed to significant depths by the high biological activity; The __map__ shows the location of areas in Europe where Chernozems are the dominant soil type.

Cover 9 % of Europe.





The major soil types of Europe

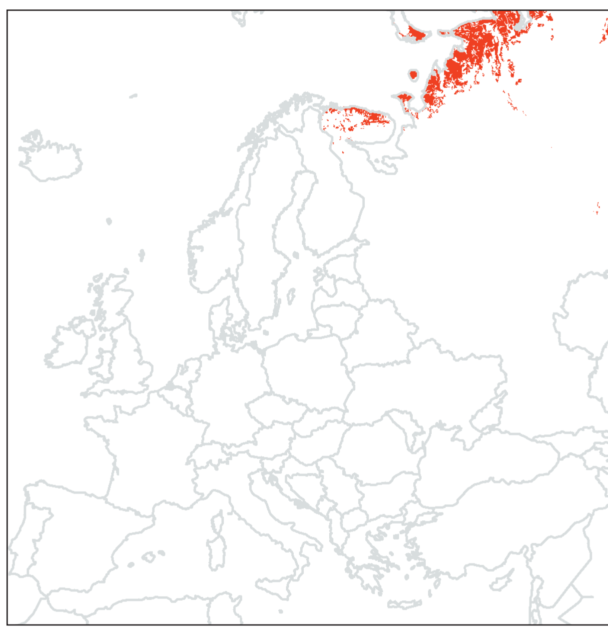
CRYSOLS

Soil of cold areas with permafrost within a depth of 1m from the surface (from the Greek *kraios*, meaning cold or ice).

Cryosols develop in arctic and mountainous regions where permanently frozen subsoil or "permafrost" is found. In this type of soil, water occurs primarily in the form of ice and cryogenic processes - such as 'freeze-thaw' sequences, 'cryo-turbation', 'frost heave', 'cryogenic sorting', 'thermal cracking' and 'ice segregation' are the dominant soil forming processes. These processes result in distorted horizons and patterned ground. These soils are widely known as Permafrost soil, Gelisols, Cryozems, Cryomorphic soils and Polar Desert soil.

Left: *patterned ground in the permafrost region of Russia, the result of sorting of soil due to freezing and thawing;* ***Below:*** *cryoturbed or distorted horizons above the permafrost; The* ***map*** *shows the location of areas in Europe where Cryosols are the dominant soil type.*

Cover 2 % of Europe.



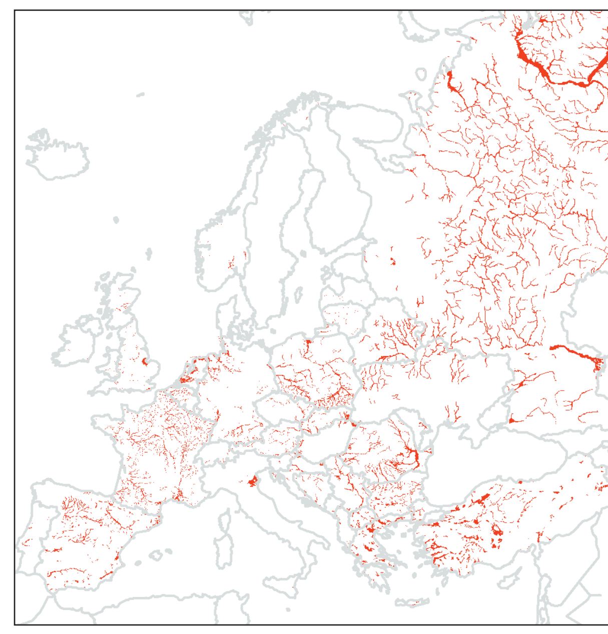
FLUVISOLS

Young soil in alluvial (floodplain), lacustrine (lake) and marine deposits (from the Latin, *fluvius*, meaning river).

Fluvisols are common in periodically flooded areas such as alluvial plains, river fans, valleys and tidal marshes, on all continents and in all climate zones. Fluvisols show layering of the sediments rather than pedogenic horizons. Their characteristics and fertility depend on the nature and sequence of the sediments and length of periods of soil formation after or between flood events. Common international names are Alluvial soil, Fluvents (Soil Taxonomy) and Auenböden (Germany).

Left: *Fluvisols develop due to the deposition of sediments following flood events - the picture shows a typical flood event where the river has overflowed its banks;* ***Below:*** *the profiles of Fluvisols show a layering of the sediments indicating deposition by water; The* ***map*** *shows the location of areas in Europe where Fluvisols are the dominant soil type.*

Cover 5 % of Europe.



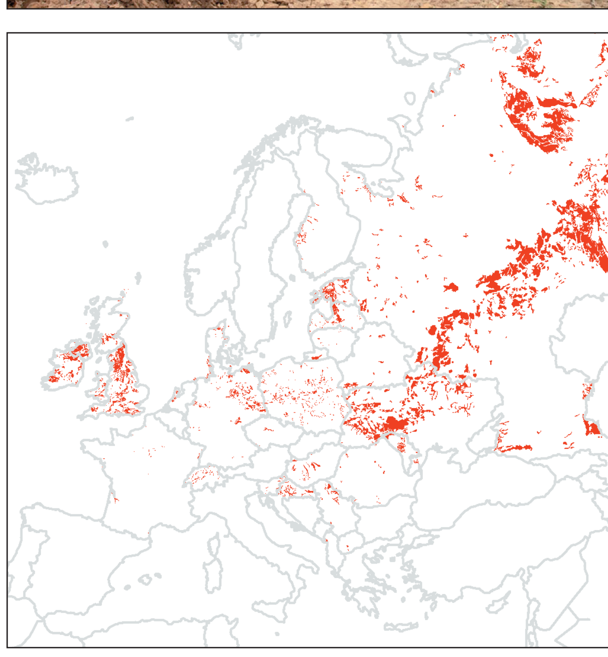
GLEYSOLS

Soil saturated by groundwater near the surface for long periods (from the Russian, *gley*, meaning 'mucky mass')

Gleysols occur mainly in lowland areas where the groundwater comes close to the surface and the soil is saturated with groundwater for long periods of time. Conditioned by excessive wetness at shallow depth, this type of soil develops gleyic colour patterns made up of reddish, brownish or yellowish colours on ped surfaces or in the upper soil layers, in combination with greyish/bluish colours inside the peds or deeper in the soil profile. Common international names are Gleyzems (Russia), Gley (Germany), meadow soil, groundwater soil and hydro-morphic soil.

Left: *Gleysols are generally not well drained and need intensive management before they can be used;* ***Below:*** *note the characteristic red and bluish /grey mottling and the presence of water in the profile pit; The* ***map*** *shows the location of areas in Europe where Gleysols are the dominant soil type.*

Cover 5 % of Europe.



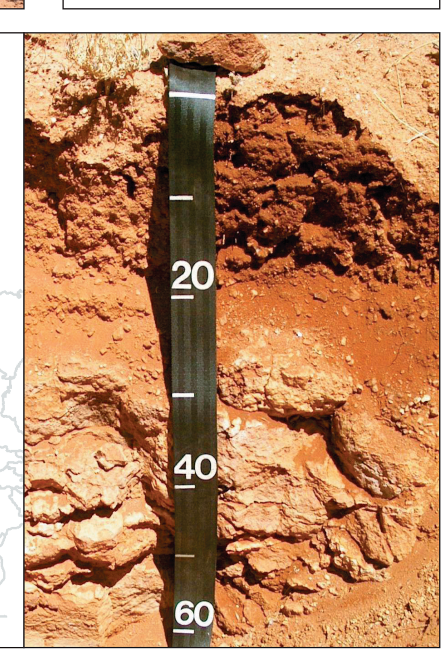
GYPSISOLS

Soil of dry areas with secondary accumulation of gypsum (from the Latin, *gypsum*, meaning the evaporite calcium sulphate).

Gypsisols have substantial secondary accumulation of gypsum in the subsurface. Most areas of Gypsisols are in use for low volume extensive grazing. They occur in the driest parts of the arid climate zone, which explains why leading soil classification systems label them Desert soil (USSR), Aridisols (Soil Taxonomy), Yermosols or Xerosols (FAO).

Left: *Arid "bush" vegetation so typical of many gypsisol regions;* ***Below:*** *The high amount of gypsum may form a petrogypsic horizon - a hardpan that further limits the use of this soil; The* ***map*** *shows the location of areas in Europe where Gypsisols are the dominant soil type.*

Dominant in only very small part of Europe (less than 0.1 %)



The major soil types of Europe

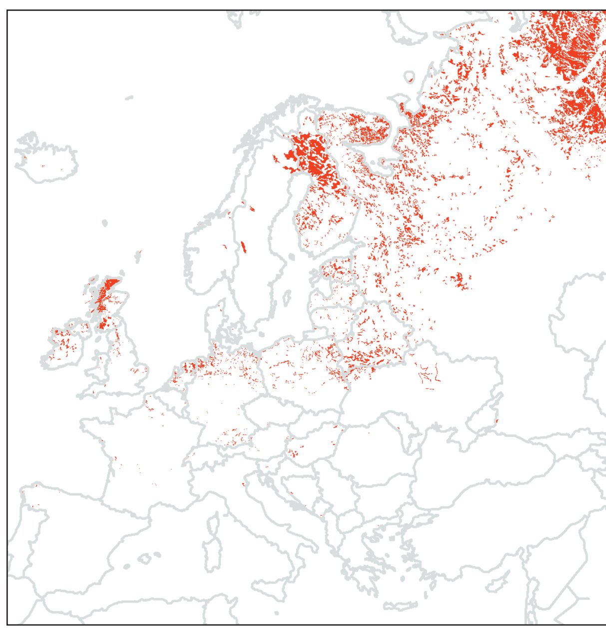
HISTOSOLS

Dark soil with high accumulation of partially decomposed organic matter generally developed in wet or cold conditions (from the Greek, *histos*, meaning tissue).

Histosols are composed mainly of organic soil material. During development, the organic matter production exceeds the rate of decomposition. The decomposition is retarded mainly by low temperatures or anerobic (low oxygen) conditions which result in high accumulations of partially decomposed organic matter. Histosols occur mainly in the boreal and sub arctic regions and are also known as peat, muck, bog and organic soil.

Left: *a typical Histosol landscape from northern Europe;*
Below: *Histosols are usually black or very dark brown and contain recognizable remains of plants; The* ***map*** *shows the location of areas in Europe where Histosols are the dominant soil type.*

Cover 5 % of Europe.



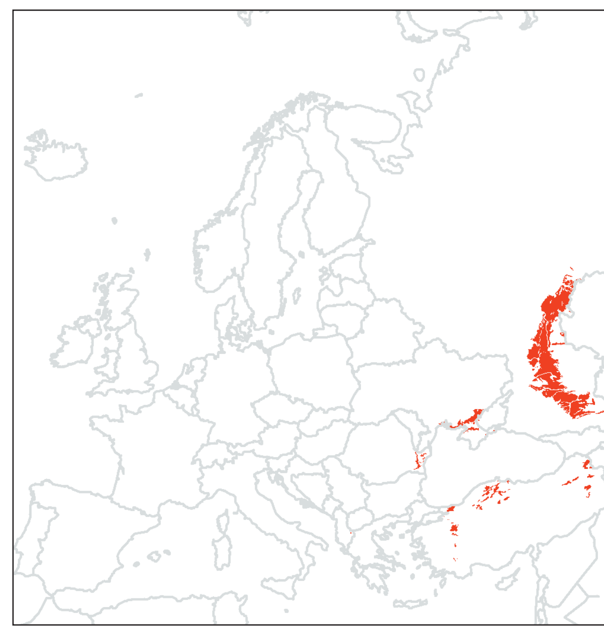
KASTANOZEMS

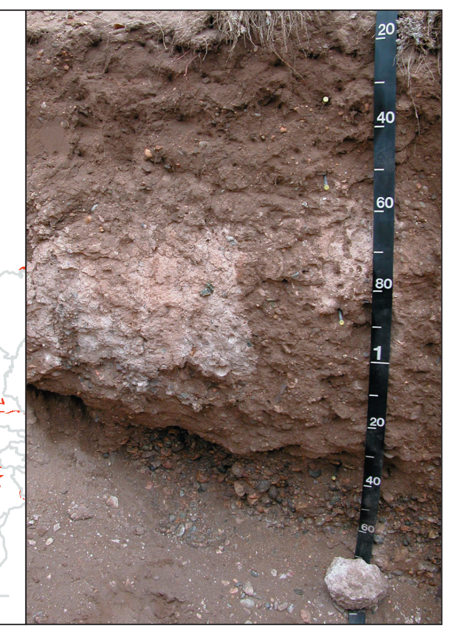
Soil with surface horizon rich in organic matter and with calcium carbonate or gypsum accumulation in subsurface horizons (from the Latin *castanea*, chestnut, and the Russian, *zemlja*, meaning earth or land).

Kastanozems have a deep, dark coloured surface horizon with a significant accumulation of organic matter, high pH and an accumulation of calcium carbonate within 100 cm of the soil surface. Kastanozems occur mainly in the dry parts of the steppe regions of the world and are shallower and lighter in colour than Chernozems.

Left: *Kastanozems being "observed" in the field;*
Below: *Secondary calcium carbonate accumulation occurs close to the surface; The* ***map*** *shows the location of areas in Europe where Kastanozems are the dominant soil type.*

Cover 2 % of Europe.





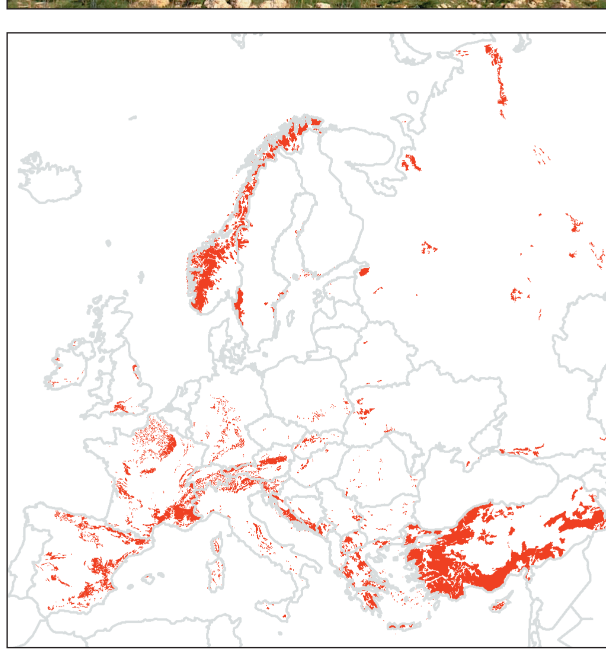
LEPTOSOLS

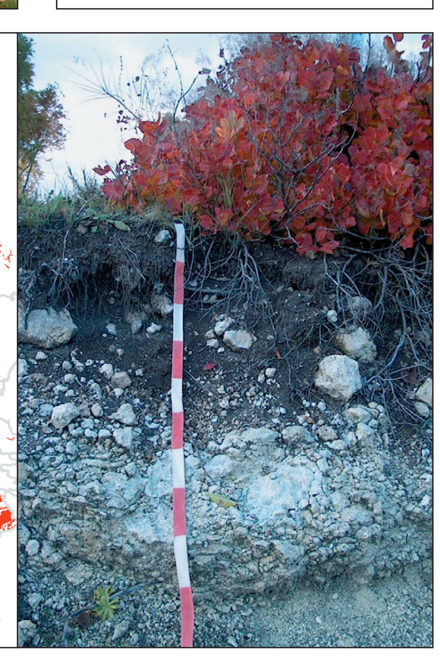
Shallow soil over hard rock or gravelly material (from the Greek, *leptos*, meaning thin).

Leptosols are shallow over hard rock and comprise of very gravelly or highly calcareous material. They are found mainly in mountainous regions and in areas where the soil has been eroded to the extent that hard rock comes near to the surface. Because of limited pedogenic development, Leptosols do not have much structure. On a global scale, Leptosols are very extensive. Leptosols on limestone are called *Rendzinas* while those on acid rocks, such as granite, are called *Rankers*.

Left: *in Leptosols, rocks are often close to the surface and many outcrops are visible;*
Below: *a Leptosol on highly calcareous material, known as a Rendzina; The* ***map*** *shows the location of areas in Europe where Leptsols are the dominant soil type.*

Cover 9 % of Europe.





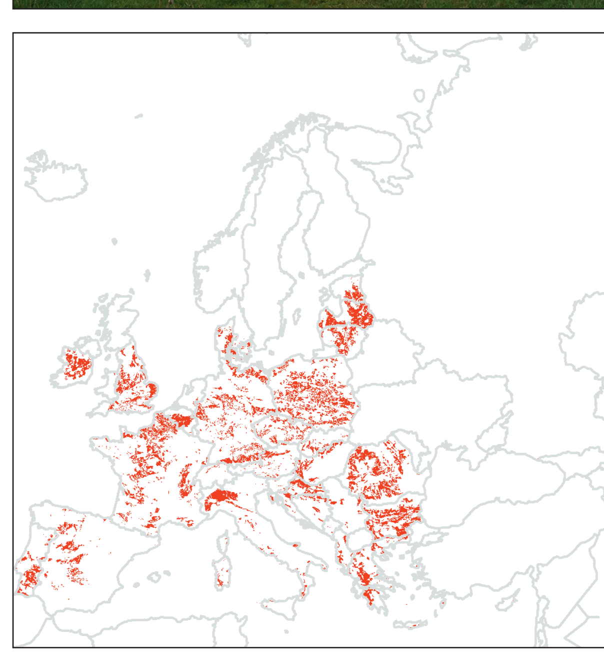
LUVISOLS

Soil with a subsurface horizon of high activity clay accumulation and high base saturation (from the Latin, *luere*, meaning to wash).

Luvisols show marked textural differences within the profile. The surface horizon is depleted in clay while the subsurface 'argic' horizon has accumulated clay. A wide range of parent materials and environmental conditions lead to a great diversity of soils in this Reference Soil Group. Other names used for this soil type include Pseudo-podzolic soil (Russia), sols lessivés (France), Parabraunerde (Germany) and Alfisols (Soil Taxonomy).

Left: *Luvisols generally occur on well drained landscapes;*
Below: *note the marked textural differentiation within the soil profile between the surface and subsurface horizons; The* ***map*** *shows the location of areas in Europe where Luvisols are the dominant soil type.*

Cover 6 % of Europe.



The major soil types of Europe

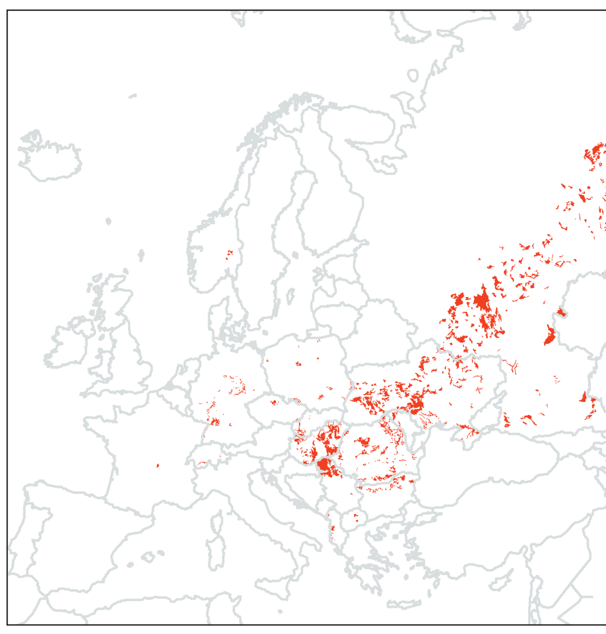
PHAEOZEMS

Soil with a deep, dark surface horizon that is rich in organic matter without secondary calcium carbonate concentrations within 1m (from the Greek, *phaios*, meaning dusk and the Russian, *zemlja*, meaning earth or land).

Phaeozems are found in wet steppe (prairie) regions and are much like Chernozems and Kastanozems but more intensively leached in wet seasons. Consequently, they have a dark, humus-rich surface horizon and have no secondary carbonates in the upper metre of soil. Commonly used international names are Brunizems (Argentina, France), Parabraunerde-Tsjernozems (Germany) and Aquolls in the order of the Mollisols (Soil Taxonomy).

Left: *Chernozems and Phaeozems are highly productive soil types and are used mainly for cereal crop production;* ***Below:*** *Phaeozems are more intensively leached than other steppe (prairie) soils and do not have secondary carbonates in the upper horizons; The* ***map*** *shows the location of areas in Europe where Phaeozems are the dominant soil type.*

Cover 3 % of Europe.



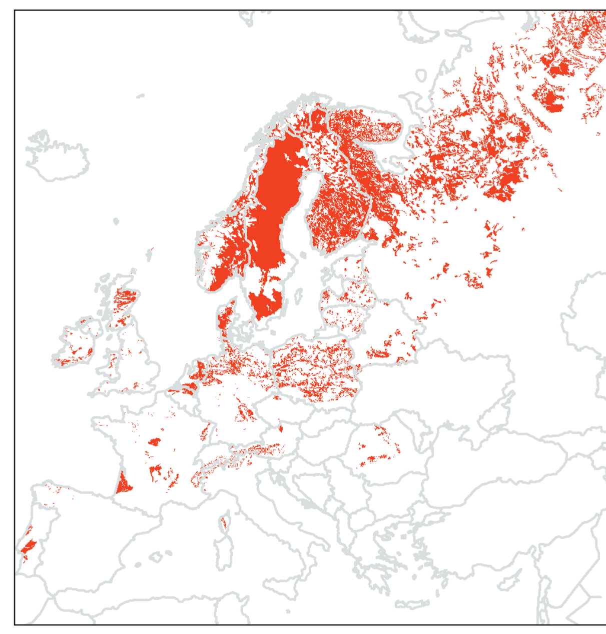
PODZOLS

Acid soil with a bleached horizon underlain by an accumulation of organic matter, aluminium and iron (from the Russian, *pod*, meaning under, and *zola*, meaning ash).

Under acidic conditions aluminium, iron and organic compounds migrate from the surface soil down to the B-horizon with percolating rainwater. The humus complexes deposit in an accumulation (spodic) horizon while the overlying soil is left behind as a strongly bleached *albic* horizon. Most Podzols develop in humid, well drained areas, particularly, in the Boreal and Temperate Zones.

Left: *Podzols are common under vegetation with acidic litter (e.g. conifer trees);* ***Below:*** *the typical contrasting leached and accumulation horizons of a Podzol - note the formation of an 'iron pan'; The* ***map*** *shows the location of areas in Europe where Podzols are the dominant soil type.*

Cover 14 % of Europe, the dominant soil of the northern latitudes.



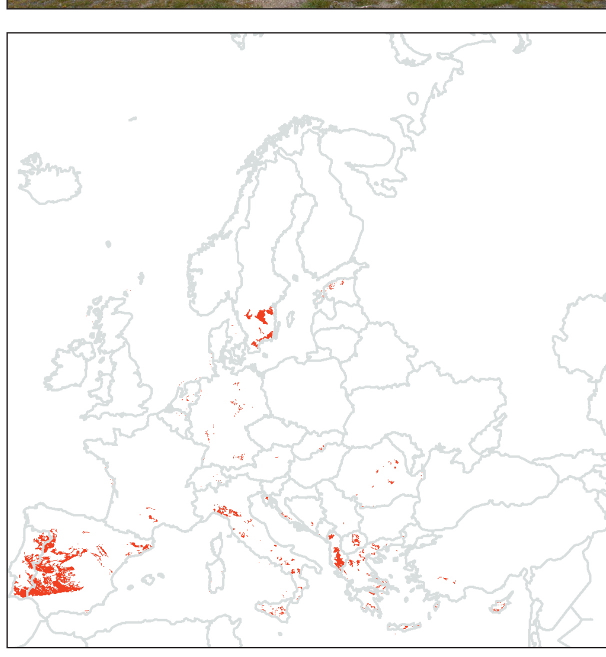
REGOSOLS

Soils with limited development (from Greek, *rhegos*, meaning blanket).

A Regosol is a very weakly developed mineral soil in unconsolidated materials with only a limited surface horizon having formed. Limiting factors for soil development range from low soil temperatures, prolonged dryness, characteristics of the parent material or erosion. Regosols form a taxonomic rest group containing all soil types that cannot be accommodated in any of the other WRB Reference Groups. Regosols are extensive in eroding lands, in particular, in arid and semi-arid areas and in mountainous regions. Internationally, Regosols are similar to Entisols (USA), skeletal soil (Australia), Rohböden (Germany) and Sols peu évolués régosoliques d'érosion(France).

Left: *Regosol is a shallow blanket-like soil - rock outcrops are often common;* ***Below:*** *Regosol profiles show thin surface horizons overlaying generally unstructured deposits; The* ***map*** *shows the location of areas in Europe where Regosols are the dominant soil type.*

Cover 2 % of Europe.



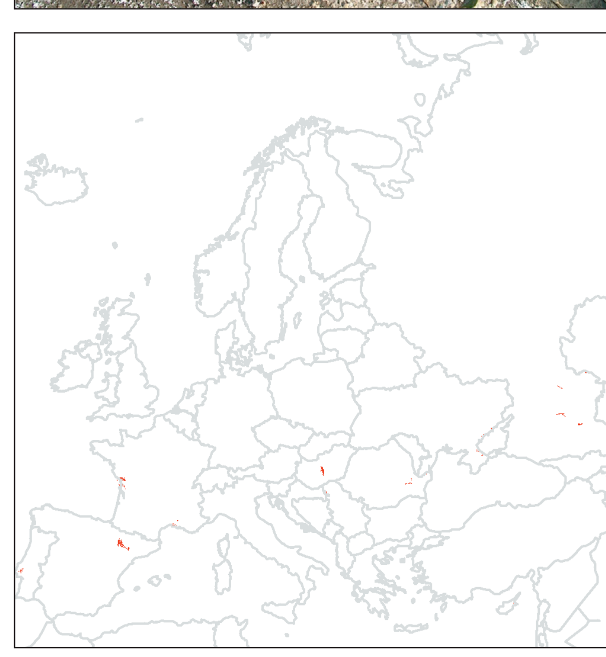
SOLONCHAKS

Strongly saline soil (from the Russian, *sol*, meaning salt and *chak*, meaning salty area).

Solonchaks are a strongly saline soil type with high concentration of soluble salts. They occur where saline groundwater comes near to the surface or where the evapo-transpiration is considerably higher than precipitation, at least during a large part of the year. Salts dissolved in the soil moisture remain behind after evaporation of the water and accumulate at or near the surface. Their morphology, characteristics and limitations to plant growth depend on the amount, depth and composition of the salts. Common international names for Solonchaks are saline soil and salt-affected soil.

Left: *after evaporation of water salts accumulate at or near the surface of Solonchaks - note the surface salt crusts and crystals;* ***Below:*** *a Solonchak with shallow saline groundwater; The* ***map*** *shows the location of areas in Europe where Solonchaks are the dominant soil type.*

Dominant in very small areas but can be very important locally.



The major soil types of Europe

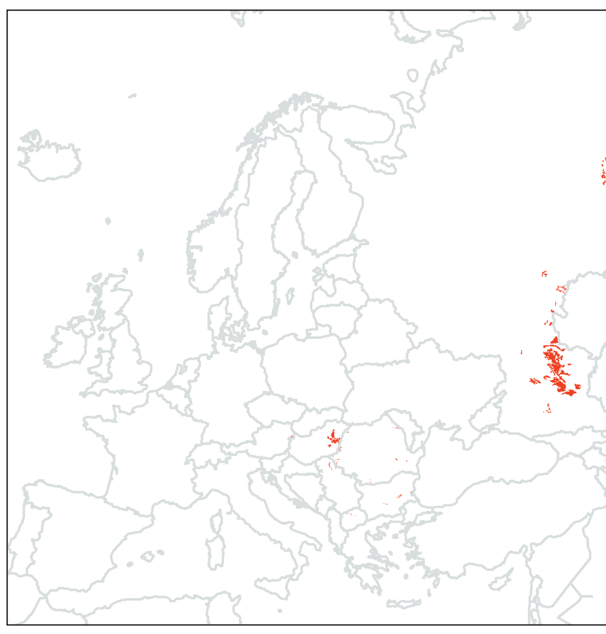
SOLONETZ

Soil with subsurface horizon of clay accumulation and high sodium content (from the Russian, *sol*, meaning salt and *etz*, meaning strongly expressed).

Strongly alkaline soil with a subsurface horizon of clay minerals, strong columnar structure and high proportion of adsorbed sodium and/or magnesium ions. Solonetz are normally associated with flat lands in a climate with hot, dry summers or with former coastal deposits that contain a high proportion of salt. Solonetz soil occurs mainly in the Ukraine, Russia, Kazakhstan, Hungary, Bulgaria and Romania. Internationally, Solonetz are referred to as alkali soil and sodic soil, Sols sodiques à horizon B et Solonetz solodisés (France), Natrustalfs, Natrustolls, Natrixeralfs, Natrargids or Nadurargids (Soil Taxonomy).

Left: *Typical landscape of Solonetz with salt crystals on the surface and salt tolerant vegetation;*
Below: *Columnar structure close to the surface of a Solonetz; The* ***map*** *shows the location of areas in Europe where Solonetz are the dominant soil type.*

Cover 0.5 % of Europe.



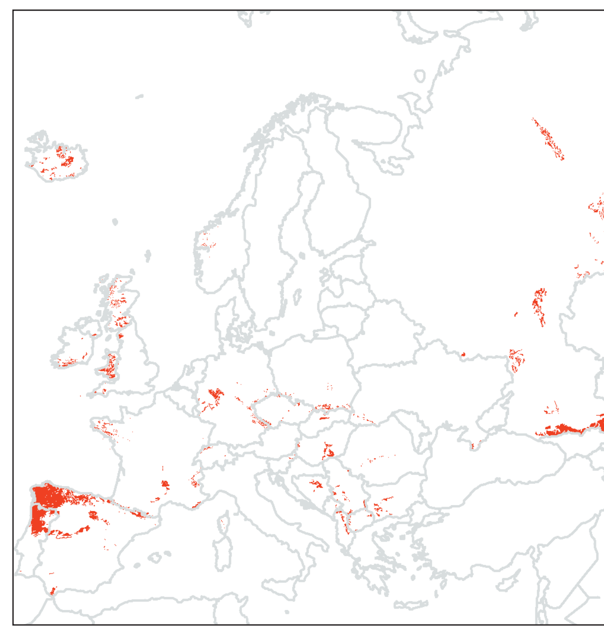
UMBRISOLS

Soil with dark, acid, surface horizon rich in organic matter (from the Latin, *umbra*, meaning shade).

Umbrisols generally develop in cool and humid climates, where precipitation considerably exceeds evapotranspiration. They are usually associated with acid parent materials. In other mapping systems, these soils are classified as Umbrepts and Humitropepts (Soil Taxonomy), Humic Cambisols and Umbric Regosols (FAO), Sombric Brunisols and Humic Regosols (France).

Left: *Umbrisols generally develop under woodland;*
Below: *Umbrisols have dark organic matter rich surface horizons; The* ***map*** *shows the location of areas in Europe where Umbrisols are the dominant soil type.*

Cover 2.5 % of Europe.



VERTISOLS

Seasonally cracking soil, rich in swelling clays (from the Latin, *vertere*, to turn).

Vertisols are rich in swelling clay minerals and occur primarily in level landscapes under climates with pronounced dry and wet seasons. Vertisols shrink and swell upon drying and wetting. Deep wide cracks form when the soil dries out and swelling in the wet season and creates polished and grooved ped surfaces (*slickensides*) or wedge-shaped or parallel-sided aggregates in the subsurface vertic horizon. The landscapes of a Vertisol may have a complex micro-topography of micro-knolls and micro-basins called *"gilgai"*. Vertisols are also known as black cotton soil (USA), regur (India), vlei soil (South Africa) and margalites (Indonesia).

Far left: *Vertisols open wide cracks in the dry season;*
Left: *Wedge-shaped aggregates and grooved ped surfaces called slickensides are common in Vertisols;*
Below: *a highly cracked Vertisol profile showing compaction of the surface horizons due to agricultural machinery; The* ***map*** *shows the location of areas in Europe where Vertisols are the dominant soil type.*

Cover 0.5 % of Europe.

Reader's Tip!

This section of the Atlas has introduced you to the 23 major soil types of Europe[1].

The **colour used in the box** surrounding the **soil group name** is the **same colour** that is **used** for that soil type in all the **maps** in the next sections of the Atlas.

In this way, when you see a **red area** (i.e. an **Andosol**) on a map then you can refer to this section find the **same colour** to see the basic characteristics of the soil, what it generally looks like and the type of landscape associated with it.

The colours used in the maps of the Atlas are based on the soil maps produced by the UN Food and Agriculture Organization (FAO) with slight modifications to clarify certain issues.

1. In this exercise, the soils of Turkey and Russia as far as the Ural Mountains were included.

All photographs in this section were provided by (EM) unless otherwise stated.

Mapping soil

Soil mapping is a difficult topic! This is because of two key problems.

Firstly, there are many purposes for which soil mapping may be carried out:

- To provide information to assist land and environmental management.
- To provide strategic information on the current status of soil quality (e.g. for national policy development).
- To provide a framework for extrapolating the results of local studies and soil monitoring networks.
- To demonstrate how local and national soil variability fits into the global pattern (trans-national policy).

The type and range of information required for each of these purposes is different although there is often a certain amount of overlap between them. Because of this, the techniques used to map soil and the information gathered during the survey can be very different, depending on the purpose for which the mapping is being carried out. In general there are two broad categories: Soil mapping for a *Specific Purpose* and *General Purpose* soil mapping.

Surveys for a specific purpose focus on quantifying the amount and spatial variation of a specific soil property or attribute. For example, the nutrient status or soil leaching potential of a field. General purpose surveys on the other hand, attempt to quantify the amount and spatial variability of a wide range of soil properties so that they can be used for many different purposes.

Most specific-purpose soil mapping is carried out within relatively small areas - one or more agricultural fields or an area of land where a former industrial activity or accident may have caused specific types of contamination. In contrast, general purpose soil mapping tends to be carried out over much wider areas ranging from the river catchment through to regional and national levels.

Map scales

The scale of a map indicates how the size of the map relates to the actual size of the area being portrayed. For a map scale of 1:100,000, 1 centimetre on the map surface is equivalent to 1 kilometre on the land surface.

Maps that are sufficiently detailed to show the positions of individual fields of a few hectares in size have scales of 1:5,000 to 1:25,000 where 1 centimetre on the map represents 50 metres to 250 metres respectively on the ground. Such maps are called 'large scale'.

At the regional or national level, maps have much smaller scales, commonly 1:250,000, but including scales of 1:100,000 and 1:400,000.

Most of the maps shown in this Atlas are taken from the 1:1,000,000 scale soil map of Europe where 1 centimetre on the map represents 10 kilometres on the land surface.

The objective of both types of soil mapping is to identify areas of land that behave in the same way. For specific purpose soil mapping, this is relatively straightforward as the information being gathered relates to a single soil property or attribute. For general purpose mapping however it is much more difficult, as the objective is to identify areas of land within which the range of characteristics is small enough to ensure that it has the same capability to carry out the various soil functions. We therefore need to define a range of characteristics within which soil can be said to behave in a similar way. There are many ways of doing this and soil scientists are still working towards identifying and defining the most effective and consistent frameworks.

The second key problem with mapping soil is that there are seldom obvious sharp boundaries between different types of soil profiles or soil properties. Soil horizons and their associated properties change continuously over the landscape, sometimes very rapidly over a short distance, but usually much more gradually over long distances. It is difficult to represent such differences on a map, where individual lines are usually used to separate one soil type or property range from another. This brings us on to the issue of scale (see box).

On small scale maps of 1:100,000 or smaller, where the width of a line on the map is equivalent to at least 100 m on the ground, the width of the transition zones that separate one soil type from another are usually smaller than the graphical accuracy of the map. However, on large scale maps of 1:5,000 to 1:25,000, boundary lines represent a 5 to 25 m zone on the ground that are usually less than the transition zone and users should always be aware of this when interpreting the information shown graphically on the soil map.

How soil maps are made

All soil maps are based on field observations. They are also based on various degrees of interpretation as to how and where the observed soil characteristics and associated soil types change between observation points. Such interpretation is based on conceptual models of how the local soil forming factors and processes determine the variation of soil characteristics across the landscape. For most of the soil maps created during the previous century, these conceptual models were never explicitly defined or quantified; they were simply based on the soil surveyors experience and observations of local soil variation. However, with the advent of the digital age and information technology, these conceptual models are increasingly being quantified and made more consistent.

Field observations are the key to making good soil maps. In most soil mapping carried out to date, the location of each inspection point is chosen by the field surveyor. Each location is selected to provide information as to how the soil characteristics being mapped vary in relation to the local geology, landscape, vegetation and climate – all factors used to develop the conceptual model of soil spatial variation. Often, inspection points are located on a straight line that crosses the landscape where the topography (how slopes vary across the landscape creating different land forms) and geology vary the greatest. In other cases, where the landscape has little variation, inspection points are located more randomly. In some cases, particularly for national 'inventory' purposes, observation points are located at pre-determined intervals on a standard grid, say at 10 km x 10 km intersects.

At each inspection point, soil characteristics are examined by either digging a small pit to reveal the profile, or by using a soil 'auger' to extract soil samples, normally to a depth of at least 1m or to rock. Each point is geo-referenced and the characteristics revealed in the soil profile are entered onto field sheets, often in the form of symbols or 'shorthand' notes. In modern soil mapping, the information is entered either directly in digital format, or onto standardized forms that are then digitized. The information recorded is based on field observation – the size and shape of soil structures, the thickness, depth and colour of each soil layer, the 'texture' of the soil estimated from its feel under moist conditions. In addition however, at a limited number of inspection points, soil samples are taken for more detailed laboratory analysis.

Students being instructed on soil description and sampling techniques (EM).

The information recorded during soil mapping by regional or national organisations is usually based on a set of standard protocols that define the type of soil characteristics to be recorded and how each characteristic is defined. Similarly, standard protocols are used to define the range of laboratory analyses carried out on each soil sample collected and the methods used for the analysis.

Once a number of field observations have been made, the field surveyor begins to develop a conceptual model of the relationships between soil characteristics and local topography, climate, geology and land use. Tentative boundaries are sketched in between different soil areas and the changes in soil characteristics between these boundaries checked by further field observation. This process usually results in amendments being made to both the conceptual model used to interpolate between points and the boundaries placed on the field map sheets. By the end of the field survey, a set of field map sheets showing the boundaries between different soil areas has been finalised.

Soil mapping unit

The soil mapping unit is the basic unit that makes up the soil map. On large-scale maps, the soil mapping unit corresponds to an individual soil type. A soil type is a specific soil with definable characteristics.

On small-scale maps, soil mapping units rarely comprise single soil types, but usually consist of a combination of a dominant soil with minor associated soils. When the various soils of a soil mapping unit occur in a recognizable geographical pattern in defined proportions, they constitute a soil association. If such a pattern is absent, they form a soil complex. Soil associations merge into a mosaic to create a soilscape.

The above photograph taken from an aircraft over the Fenland of south-eastern England clearly shows the concept of soil units and soilscape. Fluvisols of old river channels meander through the darker, organic rich peat soils that together comprise the Fens (JH).

Mapping soil

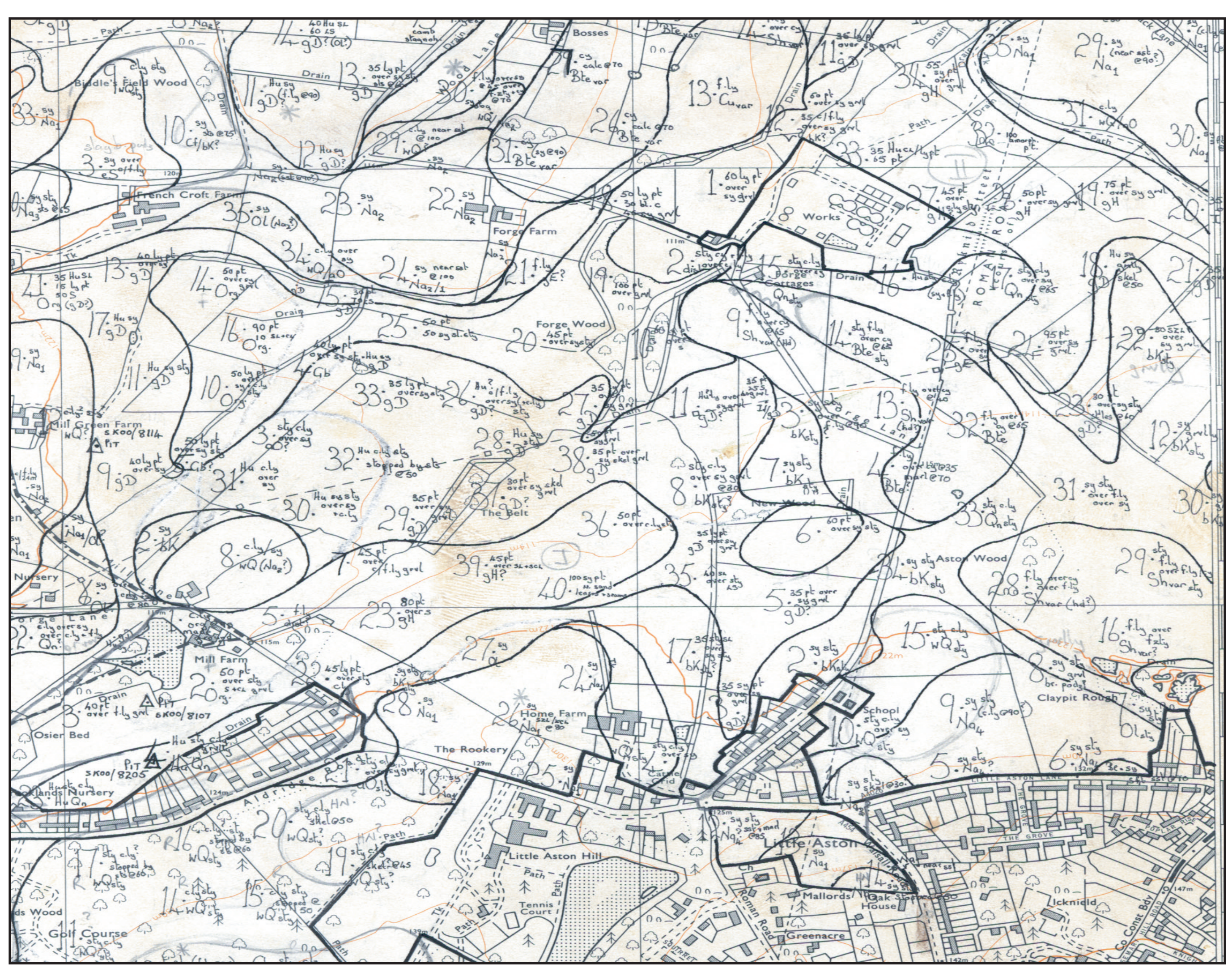
Traditional soil mapping is conducted by inspecting the soil with an auger and spade at intervals throughout the landscape. The intervals between inspections can be according to a pre-determined grid or, more often, based upon the judgement of the surveyor who uses his or her knowledge of the relationship between soil type and landscape, geology and vegetation to determine where to make inspections. Auger borings are supplemented by excavated profile pits at determined points in the landscape where boundaries between soil types occur (JH).

Until very recently, field mapping techniques to produce a soil survey had remained unchanged for the past 100 years. The five standard pieces of equipment for a soil scientist include:

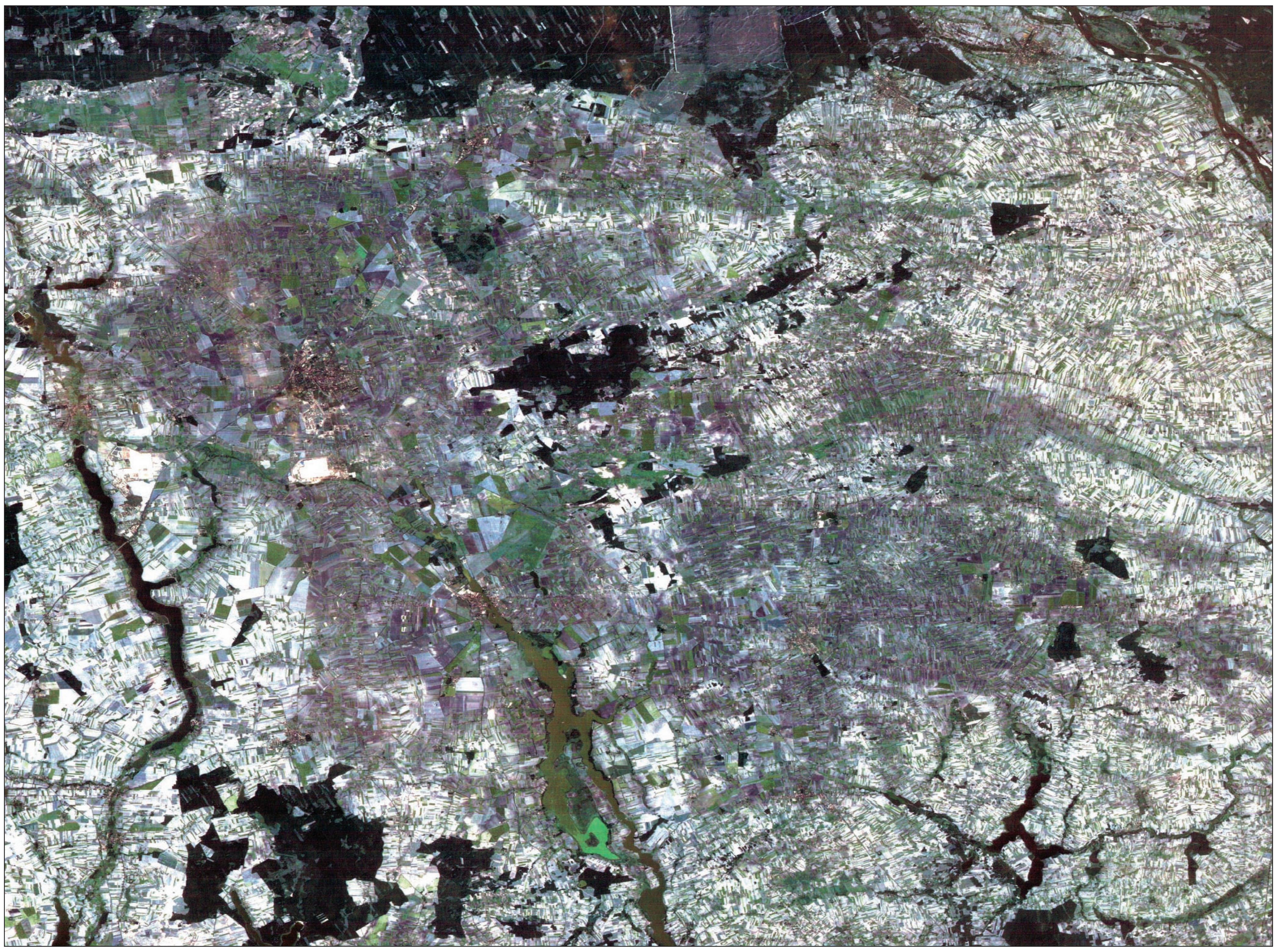
- some type of device for investigating the subsoil such as an auger (**left**) or a spade to excavate a soil profile (**above** - RJ);
- paper based maps (originally topographic but increasingly aerial photography or satellite images) on which to record field information (see **below**);
- a device to measure the slope angle (e.g. a clinometer);
- pH kits and litmus paper to measure soil acidity;
- Munsell Soil Colour Chart books to record soil colour (**bottom left**) (JH);
- A four-wheel drive vehicle to carry the soil surveyor, equipment and samples across the countryside (RJ).

More detailed investigations in the field include weighing soil fractions to calculate stoniness (RJ).

A Munsell colour chart to record the colour of the soil (JH).



A general purpose soil map field sheet constructed using free survey, soil types being delineated by hand drawn lines. The numbers indicate the position of inspection site (JH).



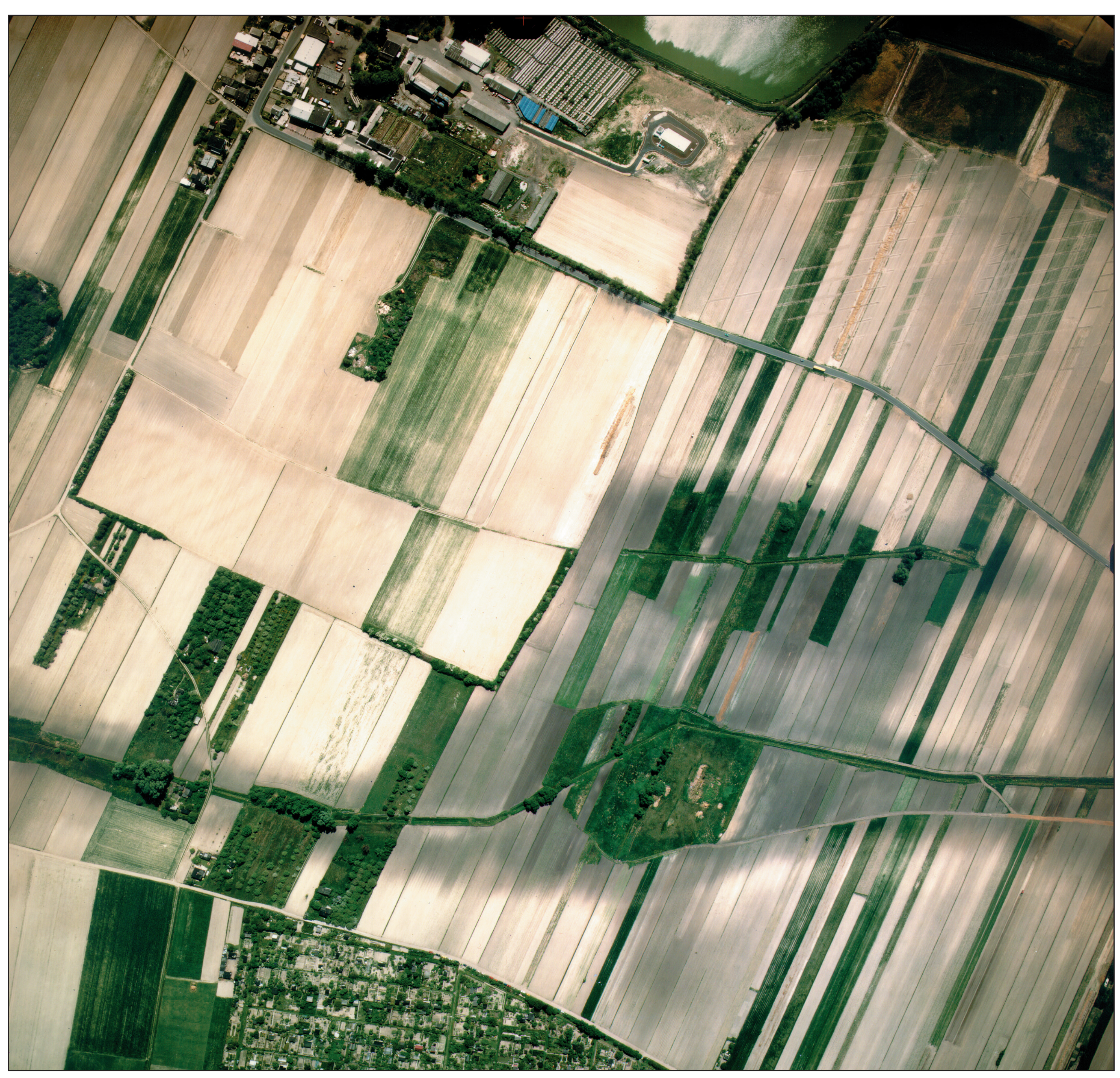
Digital mapping – the future

By using geographic information systems (see Page 97), global positioning systems (GPS) and information collected by remote sensing (i.e. sensors and cameras mounted on aircraft and satellites) to help create maps in the field, vast improvements in consistency, speed of production and accuracy will be realized.

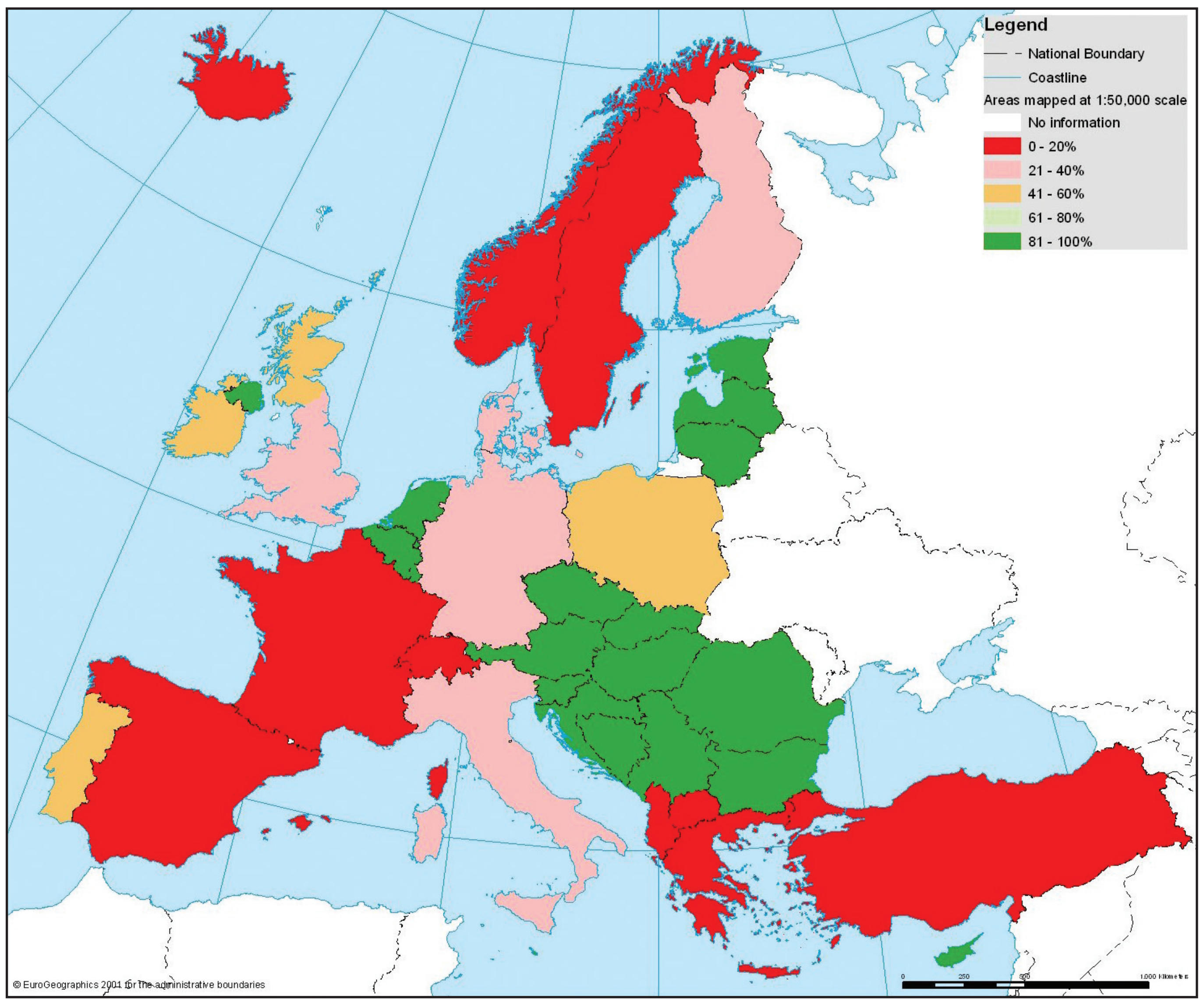
When soil is not covered by vegetation, aerial photographs and satellite images are useful for soil inventory and for analysis of soilscapes. Four main factors influence the soil reflectance in remotely sensed images: mineral composition, soil moisture levels, organic matter content and surface soil texture.

The above picture is a digital image acquired by the Thematic Mapper sensor on the Landsat Earth Observation satellite. Orbiting at an altitude of 750 km the Landsat satellite repeats its coverage of the earth every 16 days while the onboard sensors capture an image of about 185 kilometres x 185 kilometres. This scene shows an area in central Poland at the end of September when the majority of the landscape exhibits bare soil. The image clearly shows that the locations of Phaeozems (purple) contrast strongly with the bright Luvisols. Also visible are Fluvisols of river valleys that can be identified as linear green features of permanent grass pastures. The very dark areas (e.g. upper part of the image) are forested. The nominal resolution of the Thematic Mapper sensor is 30 metres (Eurimage Landsat Scene 190/23 acquired 26.09.1991 – SB).

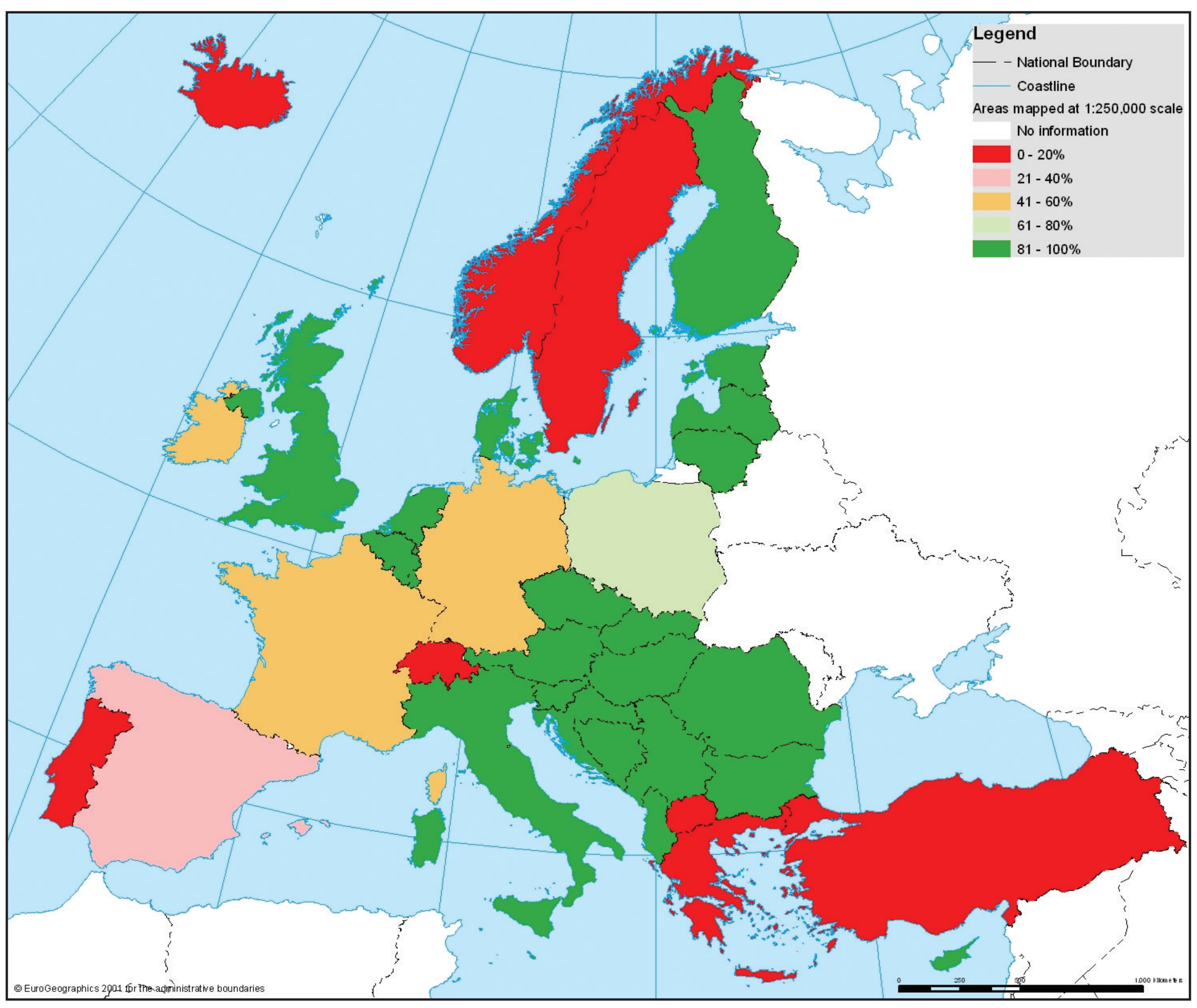
The picture on the right is a photograph taken from a special survey camera onboard an aeroplane flying at approximately 2000 metres. Using such an image and supporting fieldwork, a trained analyst can map the locations of Humic Gleysols (dark brown), Luvisols (bright) and Gleyic Luvisols (darker than Luvisols) on the image. Artificial underground drains are visible in the top-right corner of image (GUGiK Poland).



Soil maps



Availability of detailed soil surveys (1:50,000 scale or larger) in Europe (JD).



Availability of 1:250,000 scale soil surveys in Europe (JD).

Soil mapping in Europe

Many soil survey organisations in Europe were initiated post –World War II in response to the perceived need to expand agricultural output, at least to the point of self-sufficiency at a national level.

Soil maps in Europe have been prepared at a range of scales and there is little consistency between countries in the scale used or in whether the emphasis is on small or large scale mapping. It is generally accepted that as an absolute minimum each country should have a national map at a scale of 1:250,000. Any scale smaller than this is regarded of little value for in-country management of soil resources.

History of the soil maps of Europe

A number of soil scientists involved in the correlation of different soil classification systems and soil survey methods used in Europe started collecting soil data in 1952. Their initiative led to the creation of a Working Party within the United Nations Food and Agriculture Organisation whose objectives were to correlate soil nomenclature and classification in Europe and to study the application of soil surveys for land development. The first meeting of the Working Party was held in Bonn in 1957. It was realised that the best way to achieve these aims was through the preparation of a unified soil map of the continent. The preparation of such a map, at a scale of 1:2,500,000, was started in 1959 and was brought to a successful conclusion in 1965.

Conscious of its responsibilities with regard to the practical application of soil data, the Working Party, at its meeting in Florence in 1965, proposed the preparation of a Soil Map of Europe at a scale of 1:1,000,000. The sixth meeting of the Working Party was held in Montpellier in 1967, at which the study for implementing the preparation of this map was started. Among other things the meeting recommended the preparation of the legend and the definition of the soil units to be used and also to make a selection of the base map.

The group of rapporteurs, at their meeting in Poitiers in 1967, recommended that for the construction of the legend of the Soil Map of Europe at scale 1:1,000,000 advantage be taken of the experience gained with the construction of the legend for the FAO/UNESCO Soil Map of the World at a scale 1:5,000,000. It was proposed that the general principles underlying the definitions of the soil units for the Soil Map of the World be also adapted for the Soil Map of Europe. However, with regard to the larger scale of the Soil Map of Europe (1:1,000,000 versus 1:5,000,000), the existing soil units had to be further subdivided in order to reflect a greater level of detail. At the meeting of the Working Group in Varna in 1969, the general principles for the construction of the legend of this map were adopted.

In 1970 the Correlation Committee met in Ghent and prepared the "Elements of the Legend" and the participating countries were requested to prepare national maps at a scale of 1:1,000,000 using the proposed legend on the I.G.N. (Institut Gêographique National, France) map, which had been selected as the base.

The first drafts of the maps of several countries – prepared in terms of the unified legend – were discussed during the eighth session of the Working Party in Helsinki in 1971. At the ninth and last session, held in Ghent in 1973, the discussions about the common legend were finalised and recommendations were made for the completion of the map, especially with respect to the correlation of the mapping units on the boundaries of adjacent countries. This work was carried out at *ad hoc* meetings in various countries. Consequently, several countries prepared a revised version of their map in 1974 and an entirely new map was prepared for France by 1978. The Correlation Centre at Ghent University was then in possession of an up-to-date map of all EEC and many East European countries. However, at the meeting in Ghent no decisions were taken concerning the publication of the map since FAO, as a result of a stringent financial situation, could not shoulder this burden.

In 1978 the Working Group on Land Use and Rural Resources of the European Communities proposed that a Soil Map of EEC countries be prepared using the data already collected by FAO for the compilation of a Soil Map of Europe. It was also proposed that the EEC should invite Professor R. Tavernier, Chairman of the Soil Correlation Centre, Ghent, to oversee the preparation of such a map.

Following the decision taken in 1978 to prepare a Soil Map of EEC countries, an Advisory Panel with representatives from each member state was convened. Since most of the existing maps had been prepared before 1974 it was decided to update them using more recently acquired information, and because the selected base map had not proved fully satisfactory, a new one had to be sought.

The base map finally selected was the Operational Navigation Chart, in Lambert Conformal Conic projection, with Standard Parallels 57°20 and 62°40. The United Kingdom Ministry of Defence gave authority for the reproduction of ONC material for the purpose of preparing a base map for the Soil Map of the EEC countries. The Soil Map and accompanying explanatory text, published in 1985, was the culmination of more than 30 years work.

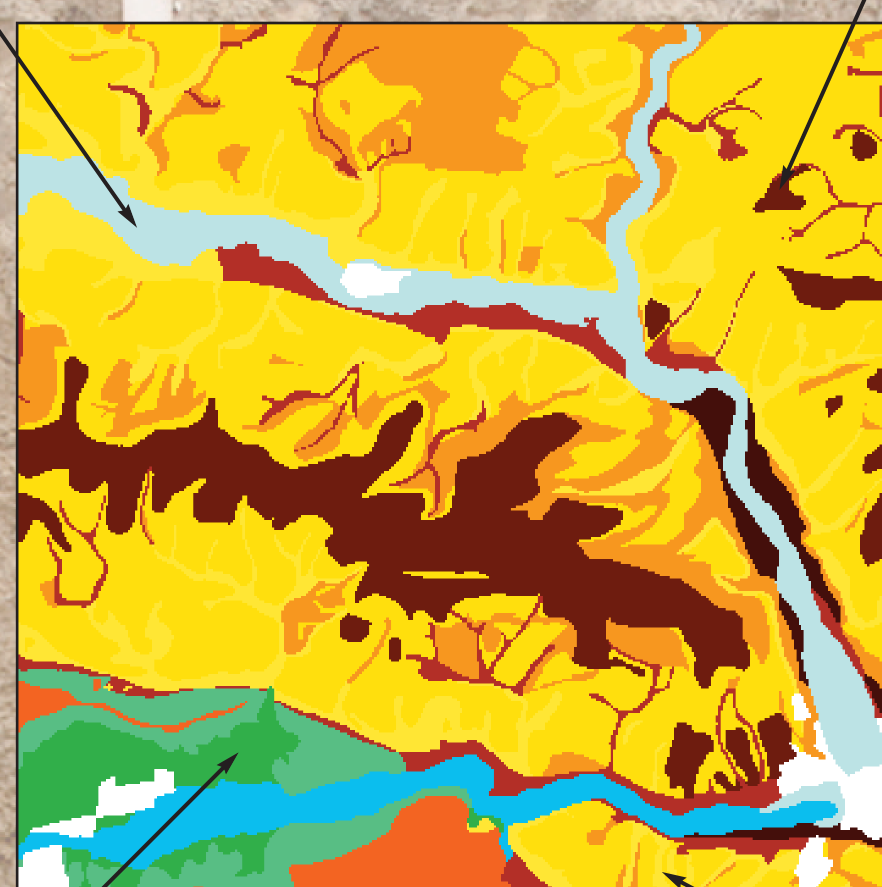
In 1986 the International Society of Soil Science published the Soil Map of Middle Europe at scale 1:1,000,000 that implied the re-editing of part of the Soil Map of the European Communities with the addition of the soil maps of Austria and Switzerland.

Soil maps of Europe

Soil is able to preserve evidence of past seismic events. This picture shows a recent normal fault cutting a soil profile on andesitic tephra near Rome. The soil on the right of the fault has dropped approximately 30 cm with respect to the in-situ material on the left (GM).

Soil and water - the essential combination for life on the planet. The above picture shows a rice crop growing in a 'paddy field' (EM).

This part of the atlas contains a series of map sheets showing the regional distribution of WRB Reference Soil Groups across Europe.



As illustrated by the above diagram (JH), a soil map depicts areas where soil properties, according to the classification scheme used, are similar. Hence, the light blue tones on the above map correspond to the top left soil profile while the yellow areas on the map correspond to the soil on the bottom right. It is important to realise that a soil map is a two-dimensional representation of a three-dimensional object and only the spatial or geographical change in soil properties is depicted.

Pages 40 and 41 present the legend to be used to interpret the regional maps while Pages 44 and 45 provide an index to the individual map sheets.