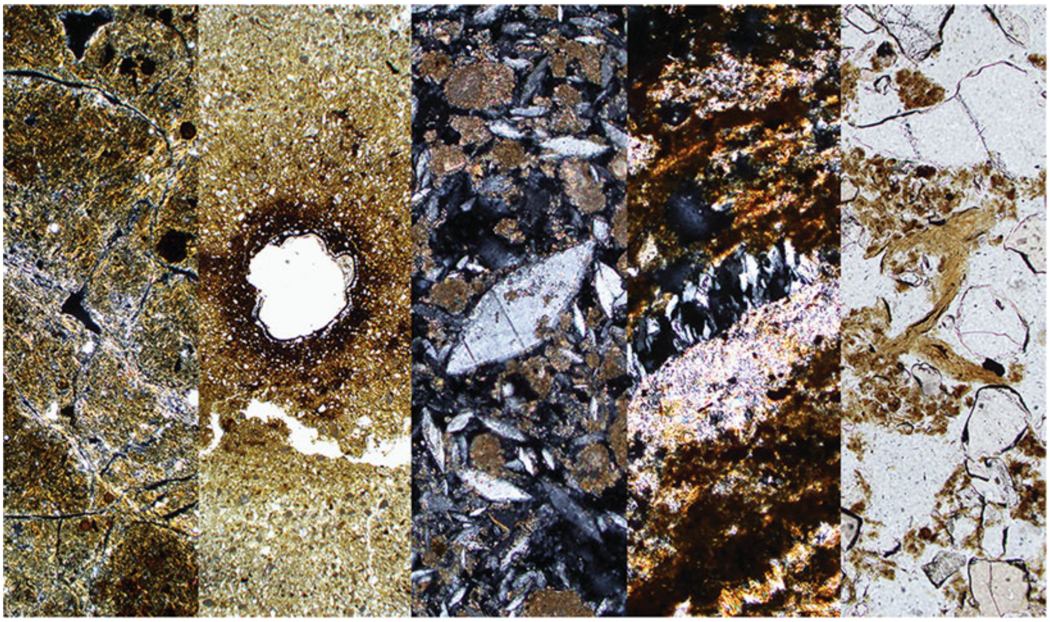
Chapter 5

Pedofeatures Associated to Soil Processes

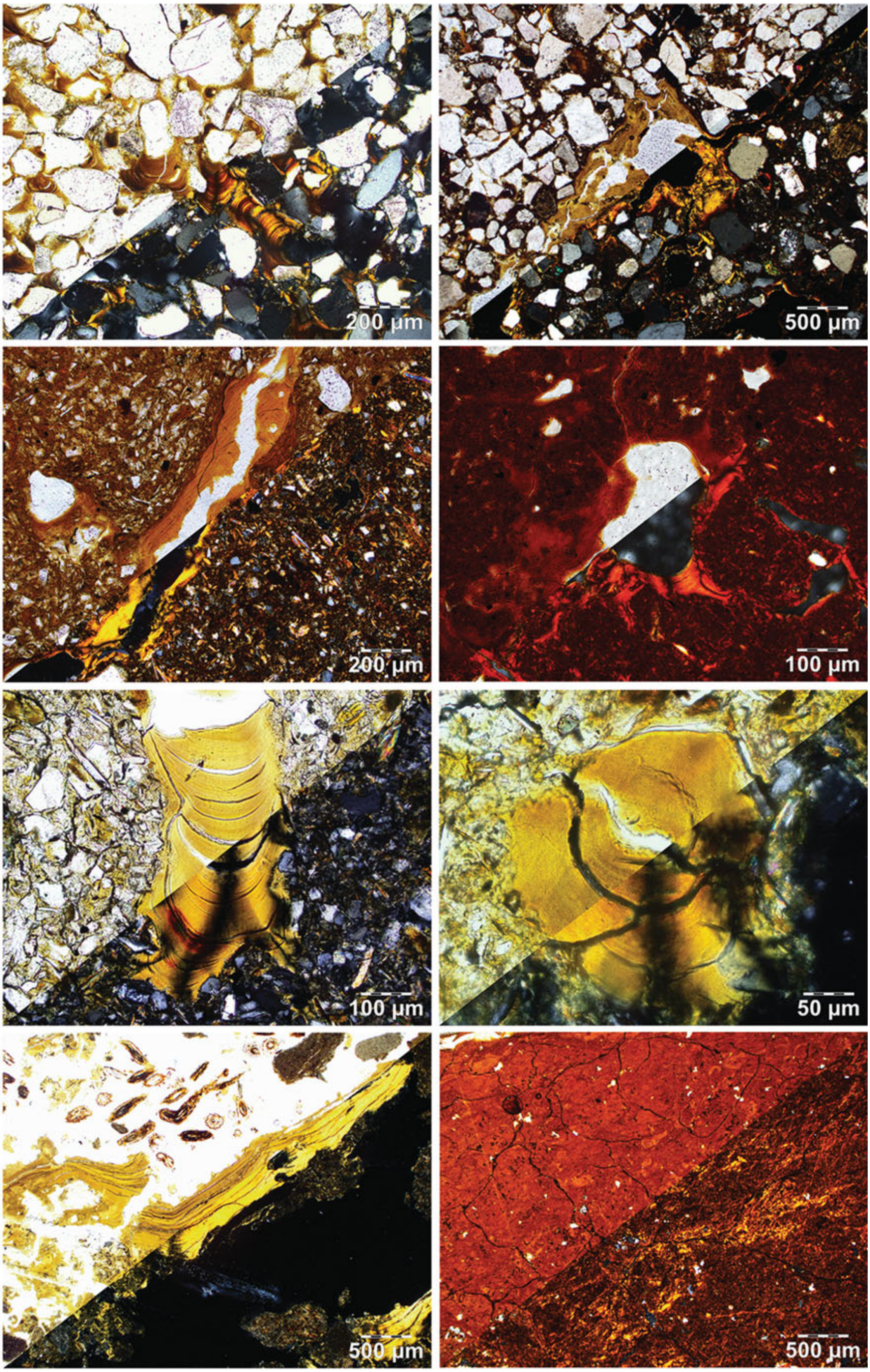
File 68: Pedofeatures and Soil Processes

As stipulated by G. Stoops, “the aim of micropedology is to contribute to solving problems related to the genesis, classification and management of soils, including soil characterization in palaeopedology and archaeology. The interpretation of features observed in thin sections is the most important part of this type of research, based on an objective detailed analysis and description” (Stoops et al. 2018). To answer such questions, two major books contributed to the comparative knowledge necessary to tackle this objective: the first one was published in 1985 and used micromorphology to distinguish between different classes of soils (Douglas and Thompson 1985); the second one is an extensive guide of more than 1000 pages to the interpretation of micromorphological features encountered in thin sections of soil (Stoops et al. 2018). The aim of this Atlas is neither to be a substitution for these books nor a way to enter directly into the interpretation of soil genesis and classification. Nonetheless, this chapter presents the imprints of major soil processes that can be easily deduced from specific features observed in thin sections. These processes involve the dynamics of (a) clay, both translocation and swelling, (b) water, such as waterlogging, evaporation, and its role as ice and frost, (c) carbonate, gypsum, and iron oxyhydroxides, and finally (d) biogeochemical reactions within the solum.



Examples of micromorphological expressions due to specific pedogenic processes: vertic material (XPL), a hydromorphic feature (PPL), precipitation of sulphate in an arid environment (XPL), clay neoformation (XPL), the influence of podzolization (PPL).

E. P. Verrecchia, L. Trombino, *A Visual Atlas for Soil Micromorphologists*,
https://doi.org/10.1007/978-3-030-67806-7_5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50 µm
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500 µm

File 69: Clay Dynamics I: Translocation

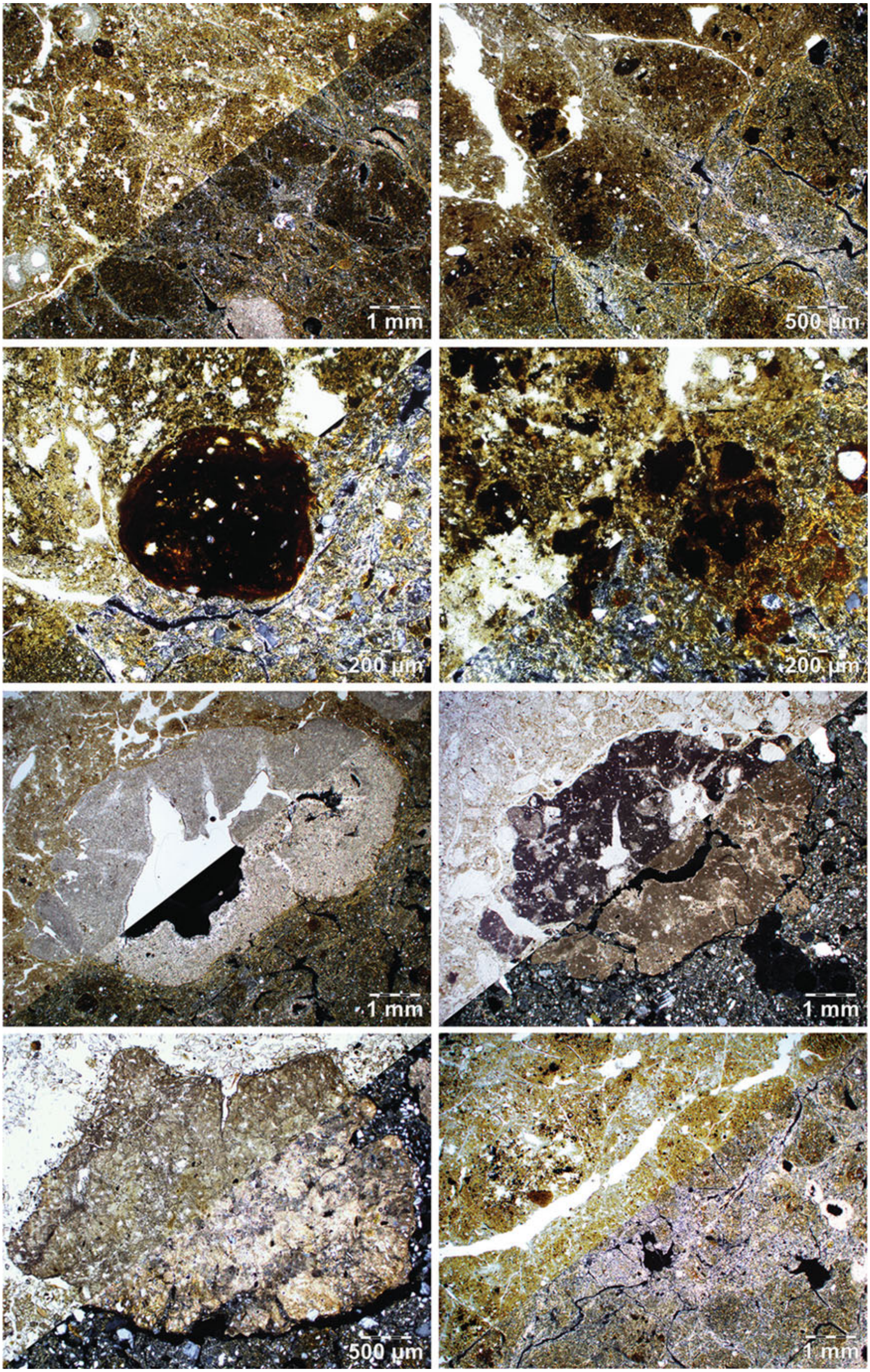
Translocation refers to the mechanical process of displacing clays (or other material) in their dispersed state, i.e. in the form of isolated particles (Schaetzl and Thompson 2015). This process is related to vertical or lateral water movements in the soil profile. It is one of the first observed processes in thin section during the last century. This process can affect a large variety of soils, changing the associated features (textural pedofeatures; see "File 56", "File 57", "File 58" and "File 61") in terms of grain size and mineralogy. The soil porosity plays a major role in translocation, i.e. in mobilization and sedimentation. In addition, the soil chemistry can also influence the dispersed state of the mineral particles. Finally, climate (including seasonality) has a distinct impact on translocation, as free percolating water is needed to displace the particles.

Captions from upper left corner to lower right corner.

1. Clay translocation forming coatings and infillings in a sandy soil. It is important to consider the type of void affected by the translocation, in this case, packing voids. During the process, the clay translocation modified the c/f related distribution from coarse monic to close porphyric, which is shown in the microphotograph. Cambisol, Paris Basin, France.
2. Clay translocation forming coatings in a soil with two grain-size modes (quartz grains and a clayey micromass). The voids affected by the translocation are mainly connecting voids, i.e. channels and vughs. Paleosol, Isle of Elba, Italy.
3. Clay translocation forming coatings in a silty soil. The voids affected by the translocation are connecting voids, i.e. channels. As the process continues with time, all the clay coatings will become infillings. Paleo-Luvisol, Piedmont, Italy.
4. Clay translocation in a clayey soil. The distinction between the pedofeatures and the micromass can be challenging due to the low contrast between the two phases. However, the use of XPL can facilitate this distinction, even if sometimes it remains difficult to distinguish between clay coatings and a striated b-fabric. Chromic Luvisol, Apulia, Italy.

5.–6. Clay translocation observed in two different directions of a cross-section: vertical (5.—laminations clearly appear) and transversal (6.—concentric fabric). Paleo-Luvisol, Piedmont, Italy.

7. After a translocation, clay coatings can be dismantled by bioturbation, which can result in fragmentation without deformation. Cambisol, Apennines, Italy.
8. Argilliturbation or shrinking and swelling of clays (Schaetzl and Thompson 2015) resulting from the integration of pedofeatures due to clay translocation into, and forming, a striated groundmass. Whatever the type of original material, a massive translocation of clays can generate argilliturbation. Paleosol, Lombardy, Italy.


1 mm
500 µm
200 µm
200 µm
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1 mm
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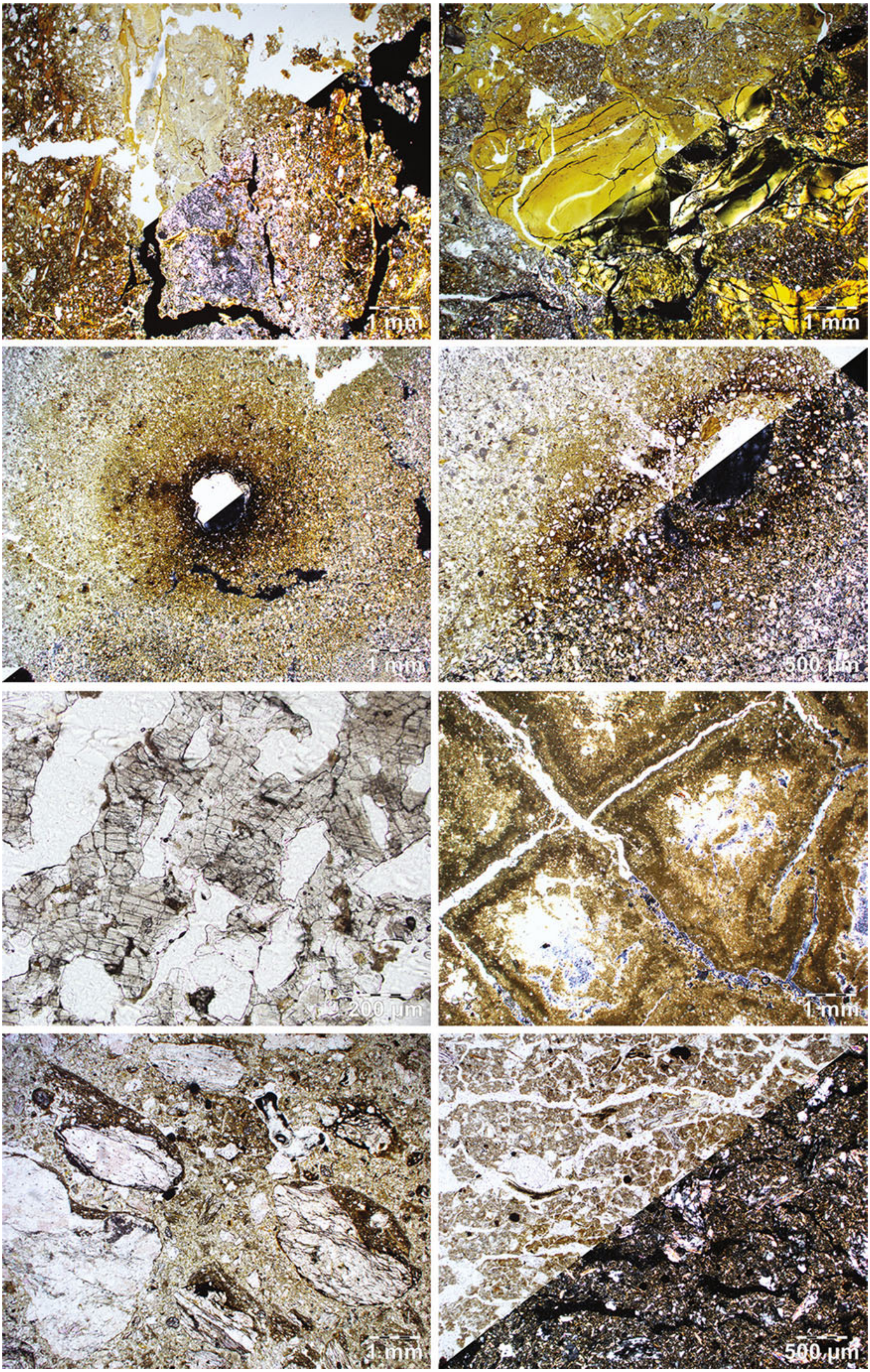
1 mm

File 70: Clay Dynamics II: Swelling

Some soils are characterized by a parent material containing a high proportion of TOT clays. Some clays have the property to shrink and swell depending on soil moisture saturation, leading to a pedogenetic process known as vertisolization and a specific class of soils, i.e. Vertisols (Duchaufour 1977; Legros 2012). Vertisols exhibit distinct characteristics, which are described in this section.

Captions from upper left corner to lower right corner.

1. General view of a Vertisol horizon in which the b-fabric is striated, a characteristic induced by shrinking and swelling of clays (see "File 69", microphotograph 8.). Vertisol, Po Plain, Italy.
2. Close-up of 1. showing slickensides (NW to SE bright light striation in XPL): these features are due to the reorientation of clays related to shrinking and swelling. For this reason, they were called "stress coatings" by Brewer (1964). Vertisol, Po Plain, Italy.
3. Iron-bearing nodule with a sharp boundary. This boundary is not due to its allochtonous origin (see "File 51") but to seasonal reworking related to shrinking and swelling of the clay micromass. Vertisol, Po Plain, Italy.
4. Iron-bearing aggregate nodule formed by the aggregation of small nodules. They are common pedofeatures of Vertisols (Stoops 2003). Vertisol, Po Plain, Italy.
5. Septaric morphology is frequent in Vertisols; in this case, it is formed by microsparitic crystals, without any evidence of groundmass impregnation: the origin of such intrusive pedofeatures remains unexplained, although a biogenically mediated process is likely. Paleo-Vertisol, Far North district, Cameroon.
6. Septaric micritic nodule showing two generations of calcitic crystals: the main fabric of the nodule is fine grained (micrite in dark brown). A second generation of cement fills some of the nodule pores with a microsparitic infilling (light grey). The most common calcitic nodules in Vertisols are micritic to microsparitic. Paleo-Vertisol, Far North district, Cameroon.
7. Nodule found in a Vertisol with a fan-like calcitic fabric. Such fabrics in nodules are uncommon but have also been observed in the geological record and described as cone-in-cone structures in pedogenic nodules (Freytet et al. 1992). Paleo-Vertisol, Far North district, Cameroon.
8. If a Vertisol is particularly enriched in a calcium carbonate phase, not only can calcitic nodules be precipitated but small calcitic crystals can also invade the micromass, forming a crystallitic b-fabric. This crystallitic b-fabric potentially obliterates the striated b-fabric described in microphotograph 1 (this section). Vertisol, Po Plain, Italy.


1 mm
1 mm
1 mm
500 µm
200 µm
1 mm
1 mm
500 µm

File 71: Water Dynamics

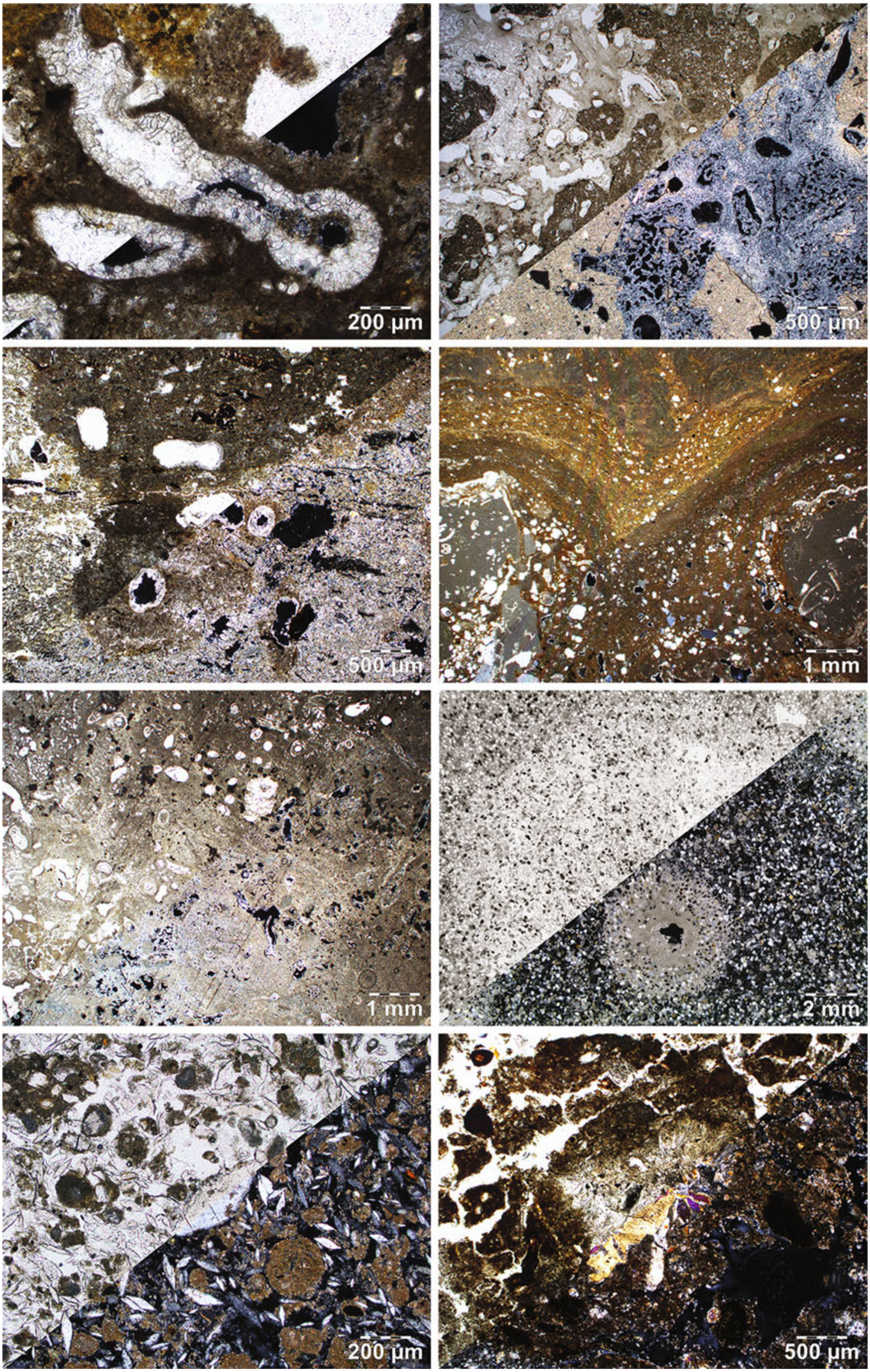
Water is the main force in pedogenesis. It influences soil dynamics in many ways. In this section, three types of water-driven processes are considered: waterlogging, evaporation, and water in freezing/thawing environments.

Captions from upper left corner to lower right corner.

1. In waterlogged soils, the presence of water precludes the infiltration of oxygen, triggering redox processes at the origin of hydromorphism (Schaetzl and Thompson 2015). In this microphotograph, iron has been reduced and removed from the micromass and the pedofeatures (coatings). This results in depletion pedofeatures (see "File 55"), which are lighter coloured compared to the surrounding material. Stagnic Luvisol, Piedmont, Italy.
2. In hydromorphic soils, it is common to find clay coatings and infillings. They usually display a whitish-grey colour and a quasi-absence of lamination and sorting (see also "File 57"). Both characteristics are due to waterlogging: the colour to the reduction of iron and its removal, and the internal structure to in situ redeposition. Soil in rice chamber, Piedmont, Italy.

3.–4. Common pedofeatures in hydromorphic soils are hypocoatings (3.) and quasicoatings (4.) developed around voids and related to iron redox dynamics (see "File 59"). The microphotographs show the influence of rootlet channels, in which oxygen could circulate, on iron distribution. Therefore, there is a gradient of amorphous iron-oxyhydroxide concentrations from the groundmass towards the void, mimicking the oxygen gradient. Fluvisols, Jura Mountains, Switzerland.

5. Precipitation of coalescent cubic crystals of halite in a Solonchak horizon due to intense evaporation of brackish groundwater. Such chloride-rich deposits correspond to an evaporitic sequence, sometimes ending with bromides. PPL view, Dead Sea shore, Israel.
6. Horizontal cross-section in a Solonetz horizon. Desiccation planes separate prismatic aggregates constituted by a core containing ghosts of halite crystals with an outer clay layer (dark brown), forming a quasicoating. Evaporation of the brackish water at the bottom of the soil induces both precipitation of chlorides and formation of large planes in a muddy micromass. Dead Sea shore, Israel.
7. In soils undergoing freezing/thawing phases, coarse cappings develop on large grains (see also "File 58"). Because of the reworking related to frost, some cappings can be detached from their supporting grains and incorporated into the groundmass or can be reoriented forming downturned cappings (van Vliet-Lanoë and Fox 2018). PPL view, Cryosol, Italian Alps.
8. Frost can induce lenticular microstructures (see "File 21") with plate aggregates (see "File 15"), resulting from the formation of ice lenses (van Vliet-Lanoë and Fox 2018). Cryosol, Italian Alps.

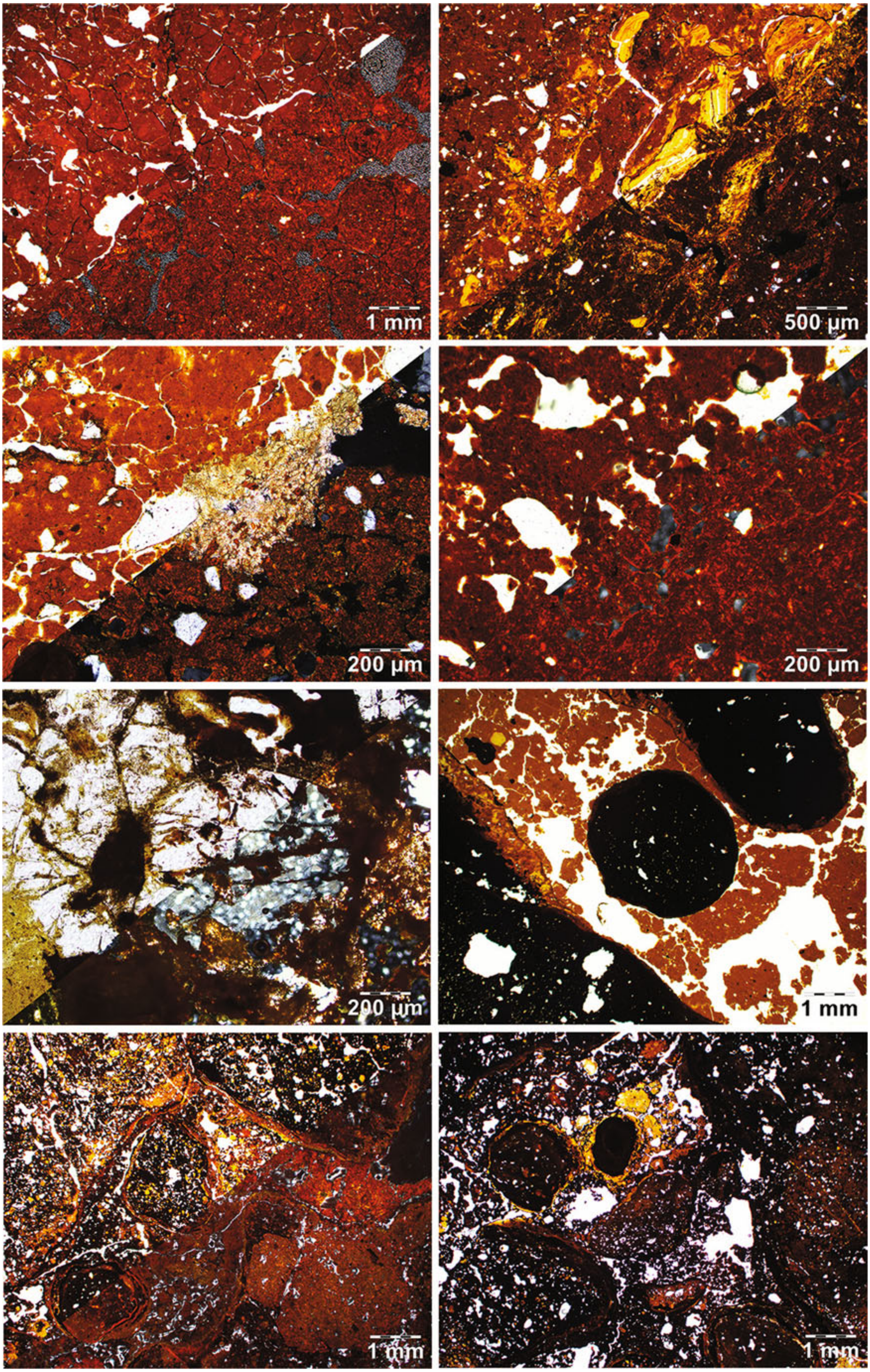

200 µm
500 µm
500 µm
1 mm
1 mm
2 mm
200 µm
500 µm

File 72: Carbonate and Gypsum Dynamics

Pedogenic carbonate-rich soils must not be confused with *calcrete*, although this confusion is widespread in the literature. Calcium carbonate redistributions in soils can occur under various climates and are not limited to the semiarid and arid zones. Indeed, large redistributions of $CaCO_3$ are caused by organisms, i.e. bacteria, fungi, roots, and animals (Durand et al. 2018). Many pedogenic carbonates result from the incorporation of soil CO_2 (Hasinger et al. 2015) and are not the consequence of a simple dissolution and reprecipitation from a carbonate parent material. Gypsum dynamics necessitate dissolution and reprecipitation of sulphate through evaporation processes. There are some exceptions related to anthropogenic influences, such as acid rain.

Captions from upper left corner to lower right corner.

1. Calcium carbonate redistribution through the action of roots. Calcified root cells (see “File 42” and “File 62”) associated to a thick micritic hypocoating have been precipitated during root activity. Fluvisol, Dorigny plateau, Switzerland.
2. Mineral infilling by needle-fibre calcite between chalk fragments (see “File 62”). Pores originate from rootlets, whereas needle-fibre calcite is precipitated by fungal filaments. Calcisol, Champagne, France.
3. Impregnation of the groundmass by secondary calcium carbonate, inducing a crystallitic b-fabric (see “File 45”). Note the presence of channels and calcified root cells. This soil is subject to water-table fluctuations. Bronze Age archaeological site, Po Plain, Italy.
4. Laminar horizon associated to a petrocalcic horizon. The laminated feature (upper half of the microphotograph) is not related to a *per descensum* process but rather to the superficial lithification of a biological mat (see “File 50”). Petric Calcisol, Negev Desert, Israel.
5. The lower part of the microphotograph has been depleted in calcium carbonate. This process is due to both dissolution during the wet season and respiration of rootlet mats. Note the presence of a convoluted fabric (see “File 62”). Calcisol, Galilee, Israel.
6. Large depletion rim, concentric to a root channel (extinct in XPL). Calcium carbonate has been redistributed from the soil groundmass (cemented by microsparite, upper part of the microphotograph) to the root channel, forming a grey micritic hypocoating (in XPL). Calcisol, Sharon, Israel.
7. Crystal intergrowths of gypsum obliterating the carbonate groundmass and disrupting aggregates. Gypsisol, Negev, Israel.
8. Recrystallization of secondary sulphate (anhydrite) after dissolution of primary gypsum. Such crystal intergrowth possibly indicates very dry local conditions. Gypsiric Leptosol, Valais, Switzerland.


1 mm
500 µm
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200 µm
200 µm
1 mm
1 mm
1 mm

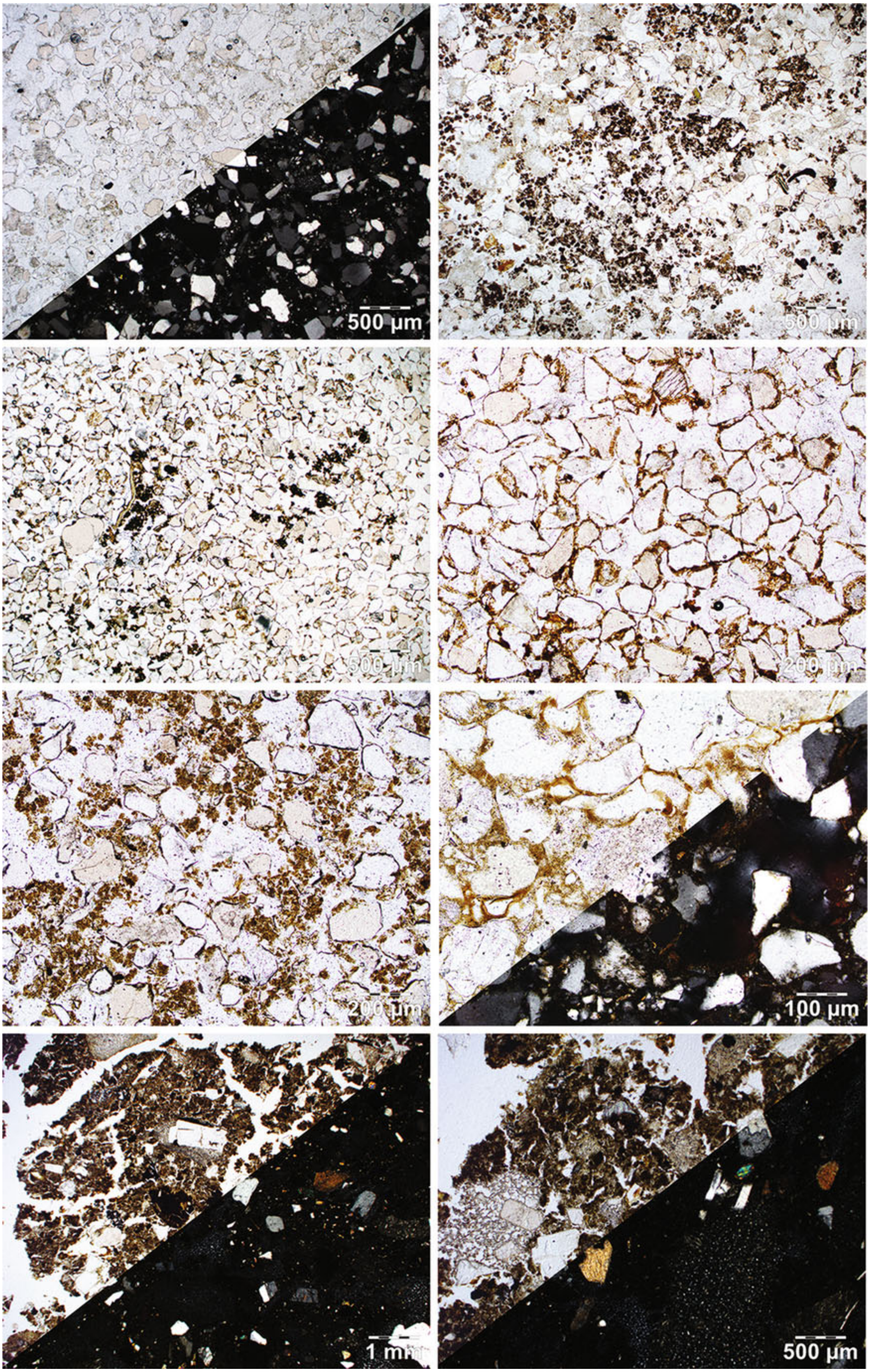
File 73: Processes Involving Iron Oxyhydroxides

Under intense geochemical weathering, oxyhydroxides can be redistributed inside the groundmass (Duchaufour 1998). This process usually turns the micromass red (rubification), which is a common trait of two distinct processes: fersiallitization and ferrallitization (Duchaufour 1977; Schaetzl and Thompson 2015). In addition, due to the strong weathering of primary minerals, clays can form and become the main compound of the micromass. An exhaustive description of mineral weathering at the microscale can be found in Delvigne (1998).

Captions from upper left corner to lower right corner.

1. Red homogeneous and clayey micromass due to the process of rubification in a fersiallitic soil. Note the low birefringence of the b-fabric. Rhodic Luvisol, Apulia, Italy.
2. Clay coatings due to clay translocation inside a fersiallitic soil. Clay translocation can also affect rubified soils subjected to high seasonal temperature and moisture variations. The clay accumulation leads to the formation of stress-deformed clay coatings due to argilliturbation (see “File 69”). Paleo-Chromic Luvisol, Lombardy, Italy.
3. During the dry season, calcium carbonate can precipitate in fersiallitic soils. Such carbonate nodules are often microsparitic. Paleo-Chromic Luvisol, Lombardy, Italy.
4. In the presence of kaolinite (a TO clay), round sand-sized micro-aggregates of oxyhydroxides and clays form, inducing a specific microstructure called “pseudo-sand” (Ahn 1970), which is typical of a ferrallitic soil. Acrisol, Mongodara district, Burkina Faso.
5. Weathering of a quartz grain forming a “runiquartz” (Eswaran et al. 1975). Parts of the quartz grain are infilled by oxyhydroxides (dark brown micromass). Paleosol, Ligurian coast, northern Italy.
6. Large nodules of iron oxyhydroxides (in black) surrounded by a clay micromass (light brown). This type of structure appears inside tropical soils, which are not yet completely encrusted by iron oxyhydroxides. PPL view, Plinthosol, Mongodara district, Burkina Faso.

7.–8. Typical characteristics of iron-encrusted tropical soils containing coalescent oxyhydroxide nodules and partially surrounded by clay coatings. In 8., only PPL view, showing the dense oxyhydroxide composition of some nodules and the groundmass. Plinthosol, Fort Portal district, Uganda.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200 µm
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100 µm
1 mm
500 µm

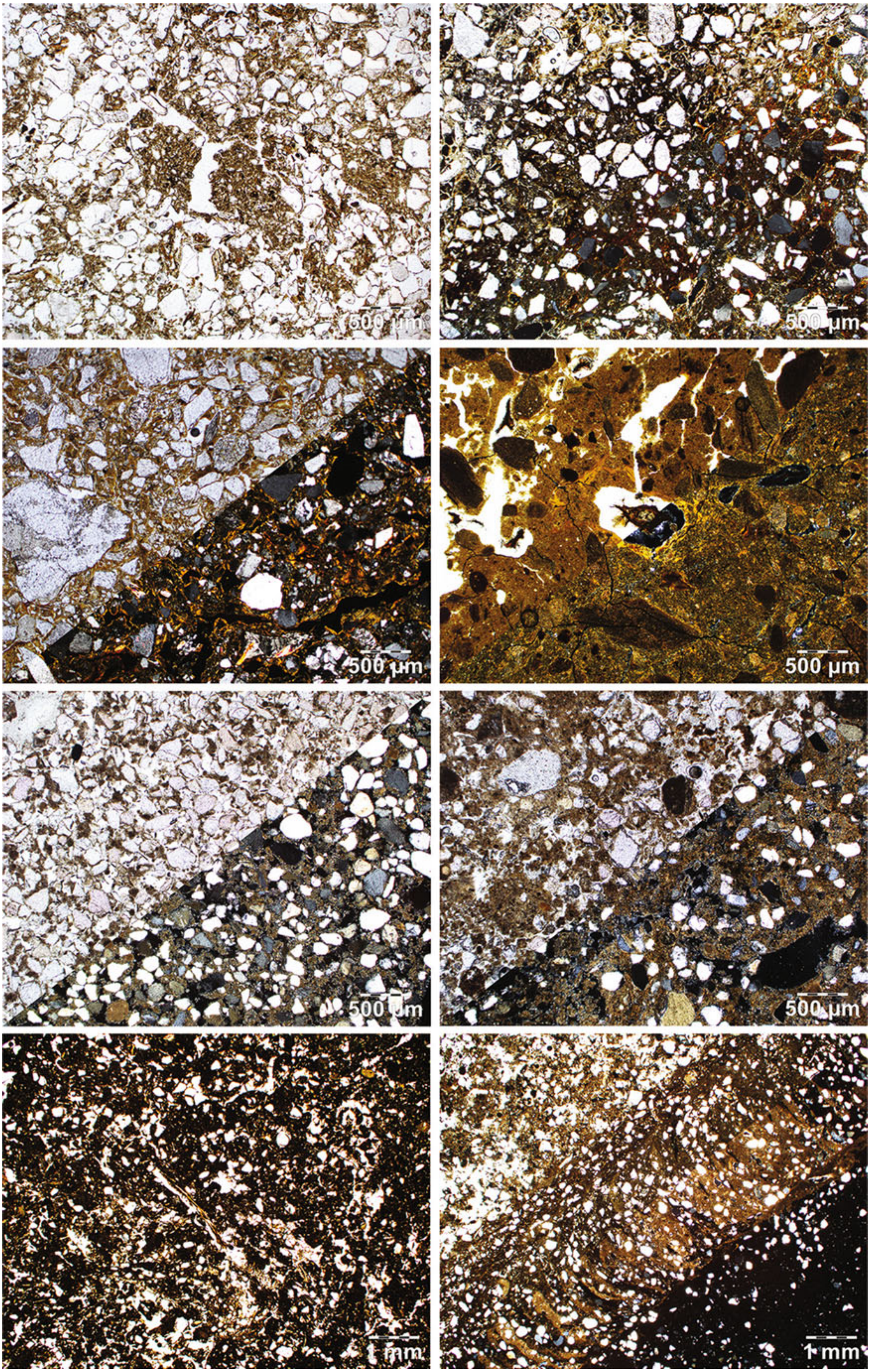
File 74: Biogeochemical Processes I

During biogeochemical processes, organic matter can combine with mineral compounds to form organomineral complexes that give soils specific properties. In addition, organic matter constitutes a driving force of pedogenesis as it influences the processes of weathering, as well as the transfer of matter inside profiles (Duchaufour 1997). In soil micromorphology, podzolization and andosolization are clearly expressed by specific features. In the case of podzols, horizons display striking micromorphological differences, while in andosols, micromorphological characteristics are found more in the general aspect of the thin section.

Captions from upper left corner to lower right corner.

1. Eluvial E horizon made of loosely packed quartz grains in a coarse monic c/f related distribution. Note the absence of mineral fine material and organic constituents. Podzol, L'Isle-Adam forest, Paris Basin, France.
2. Bh horizon showing a coarse groundmass made of quartz grains associated with an organomineral micromass organized in micro-aggregates in an enaulic c/f related distribution and referred to as polymorphic material (Van Ranst et al. 2018). Podzol, L'Isle-Adam forest, Paris Basin, France.
3. Bhs horizon showing a coarse groundmass made of quartz grains associated with clusters of dark organomineral matter organized in micro-aggregates. Some brownish material starts to bridge quartz grains, making the c/f related distribution intermediate between enaulic and gefuric. PPL view, Podzol, L'Isle-Adam forest, Paris Basin, France.
4. Bs horizon with quartz grains coated by yellowish to dark brown monomorphic Fe- and/or Al-rich material (Van Ranst et al. 2018), slightly cracked or uncracked. Coatings can include amorphous organic matter. The c/f related distribution is chitonic. PPL view, Podzol, L'Isle-Adam forest, Paris Basin, France.
5. Bs horizon showing an enaulic c/f related distribution with polymorphic fine mineral material mixed with oxyhydroxides. Such soils are intergrades between Cambisols and Podzols (Duchaufour 1997). PPL view, Entic Podzol, L'Isle-Adam forest, Paris Basin, France.
6. Same horizon as in 5. but characterized by a chitonic c/f related distribution with a very fine monomorphic mineral micromass, also forming coatings. Entic Podzol, L'Isle-Adam forest, Paris Basin, France.

7.–8. In these thin sections, the micromass is totally extinct. Only some coarse mineral grains can be identified in XPL (e.g. amphiboles; see "File 33"). This extinction is due to the amorphous composition of the micromass, which is dominated by allophanes and other short-range order minerals associated to organic matter. Andosols, Chaîne des Volcans, Massif Central, France.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500 µm
500 µm
500 µm
1 mm
1 mm

File 75: Biogeochemical Processes II

Brunification is a common biogeochemical process observed in temperate regions, during which clay minerals, iron, and organic matter interact to form clay–humic and clay–iron complexes. In environments with more pronounced contrasts between seasons, another type of biogeochemical process prevails, i.e. the deep incorporation of stable organic matter forming isohumic profiles. Unfortunately, soil micromorphology cannot provide any clear and univocal sets of diagnostic features for such kinds of processes. In this section, only a few examples of micromorphological aspects of soils under brunification and melanization are given.

Captions from upper left corner to lower right corner.

1. Quartz grains in a light brownish micromass composed of fine mineral material and organic matter, forming an irregularly-spaced porphyric c/f related distribution. PPL view, Dystric Cambisol, L'Isle-Adam forest, Paris Basin, France.
2. Quartz grains in a light to dark brownish micromass composed of fine mineral material and organic matter, forming a single-spaced porphyric c/f related distribution. In XPL, the birefringence pattern suggests an early phase of clay coating formation. Gleyic Cambisol, L'Isle-Adam forest, Paris Basin, France.
3. Coarse mineral grains in a clayey micromass forming a single-spaced porphyric c/f related distribution. The b-fabric is granostriated, and clay coatings are easily observed in XPL. Luvisol, Jura Mountains, Switzerland.
4. Brunification and clay translocation (see "File 69") can often be associated during soil evolution. Thin clay coatings formed in this brown groundmass made of clays, oxyhydroxides, and mixed with claystone fragments. They are easily identifiable by their specific birefringence. Paleo-Luvisol, Apennines, Italy.
5. Micro-aggregates formed by organic compounds and fine mineral matter. This porphyric c/f related distribution emphasizes the homogeneity in this thin section. Kastanozem, Chobe Enclave, Botswana.
6. Micro-aggregates of organic compounds mixed with fine minerals. Pellets and bio-aggregates are characteristic traits of this soil and are due to bioturbation by termites. Kastanozem, Chobe Enclave, Botswana.
7. Dark micromass composed of organic matter and fine material, forming a close porphyric c/f related distribution. The colour and the fabric are typical of a melanization process. PPL view, Chernozem, Chobe Enclave, Botswana.
8. Bow-like passage feature in a Chernozem, probably generated by termite bioturbation. This pedofeature (see "File 63") has a specific fabric, in which crescent-like layers are stacked. Chobe Enclave, Botswana.