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The role of paleosols in paleoenvironmental studies: genesis and development of Apennine mountain soils during the Holocene.

Ph.D. Thesis

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“And wow! Hey! What’s this thing suddenly coming toward me very fast? Very, very fast. So big and flat and round, it needs a big wide-sounding name like … ow … ound … round … ground! That’s it! That’s a good name—ground!

I wonder if it will be friends with me?”

Douglas Adams, “The Hitchhiker's Guide to the Galaxy”

Contents

Abstract

The aim of this research is to conduct an investigation on the soils, paleosols and landforms of the area of Mt Cusna ridge (Northern Apennines - Italy) in order to define the relationship between geomorphic evolution and soil development, to characterise the main pedogenetic processes and factors acting on soils in past and present times, and to provide new information to understanding the Holocene climatic variations in the area. For this purpose, several sets of field, laboratory and microscopic analyses were carried out.

A comprehensive survey of the study area allowed the production of a geomorphological map (scale 1:10000, attached to this thesis) expanding and revising the existing cartography (Panizza et al., 1982). At the same time, also the soils were surveyed and described, in order to provide a detailed characterisation of the soil types of the area. Selected soil profiles were sampled and underwent a wide set of laboratory analyses, including measurements of pH, exchangeable bases and cation exchange capacity (CEC), organic carbon content, total nitrogen and exchangeable phosphorus; along these iron oxides were investigated with the measurement of total iron and its extractable forms; grain size analyses and x-ray diffractions on the clay fraction were also carried out; finally, micromorphology of soil thin sections and SEM observations and analyses were also carried out on a subset of significant horizons.

Geomorphological survey results allowed to compare the active and inactive processes. Glacial and periglacial processes, though mainly inactive since the beginning of the Holocene, still give an important forcing on the present landscape through their deposits, produced during the Last Glacial period. During the Holocene, different phases of stability and instability could be detected from the activation an reactivation of slope dynamics as the result of both climate fluctuations and structural constraints. The result is a very diversified landscape in which erosion and deposition alternate in space and time. The present day conditions are characterised by a prevalence of washout and erosion activity, mainly on lithologies more susceptible to surface processes.

Soils were attributed to different landscape units, highlighting differences in processes and development between them. Degree of pedogenesis, in fact, varies from weakly developed soils on the highest and steeper areas to deep and more weathered profiles at lower elevations and/or on flatter surfaces. Among the latter, the presence of a paleosurface, characterised by the presence of paleosol units truncated and buried by colluvial deposits, has been detected in the stable areas above 1650 m a.s.l..

Laboratory geopedological analyses showed how soil in the area are characterised by being mainly silty-clayey, with low values of pH and organic C which tends to concentrate at the surface and in many cases also in the uppermost horizon of buried soil units. Iron oxides are usually present in its crystalline form, with some exceptions in peculiar soils. The crystalline/total iron ratio (weathering index) is generally low, higher inside paleosurface buried units. Clay fraction mineralogy shows the presence of quartz and chlorite inherited from parent material; neoformed clay minerals consist in illite and mixed layer clays.

Micromorphological analysis mainly involved paleosurface horizons. Colluvial units show the presence of variable quantities of pedorelicts (Brewer, 1967) in their groundmass, as well as features pointing to multiple depositional events. The buried unit shows different phases of clay illuviation relatable to environmental changes. In flat areas a 2Ab horizon is found between the two units, showing accumulation of excrements and organic material; features of frost action are also present. Particular conditions are related to higher elevations as well as areas with steeper slopes.

Data obtained from field and analytical approaches allowed to outline the main pedogenetic processes acting in the area. Pedogenesis started since the glacial retreat: clay mineralogy and iron oxide content are compatible with a soil formation taking place during the Holocene. The main active process in the area is Brunification (Duchaufour, 1983), which drive the development of Regosols and Cambisols (FAO, 2014); these soils are better developed at lower elevations on flat areas and stable deposits, whereas soils on steeper slopes and higher elevations show evidences of a weaker pedogenesis. Luvisols (FAO, 2014) were also formed in the past and are mainly preserved as paleosols of the buried units related to the paleosurface; moreover the clayey pedofeatures of these paleosols allowed the identification of three different clay illuviation phases, preceding the Subboreal climatic recrudescence ^{14}C dated (Compostella et al., 2012; Giraudi, 2014).

During the Late Holocene in the area appears Podzolisation (Duchaufour, 1983) as a secondary process, as testified by the presence of cryptopodzolisation features in soil profiles from different areas. Traces of this process could be also found inside the 2Ab horizon, marking the top of the buried unit in some soil profiles surveyed on the paleosurface; this horizon can be characterised as an accumulation of insect excrements and organic material developed in cold conditions. A change in vegetation cover detected by anthracological assemblages (Compostella et al., 2012) seems to confirm this hypothesis. ^{14}C dating (Compostella et al., 2012) and frost features inside the 2Ab horizon date its burial to the Little Ice Age (LIA), which marks a phase of general erosion causing colluvial deposition also in flatter areas, which probably happened in multiple events through time. The colluvial layers show apparent pedogenesis caused by the presence of pre-weathered soil material and signs of homogenisation probably related to cryoturbation processes. Finally, the presence of frost and solifluction features inside these recent soils point to the characterisation of the LIA as a drier period in which winter precipitation were less abundant and snow cover thinner.

This study outlined the existence of complex interactions between pedogenic, geomorphic and environmental processes throughout the Holocene. The influence of these aspects on soil features could be detected and used to describe and interpret the present landscape in the light of its modifications through time.

Chapter 1

Introduction

The theme of climate change and its possible consequences is a matter of debate and interest at worldwide scale; the study of the environmental scenarios that took place as a result of Quaternary climatic variations is a valuable support in hypothesising the potential environmental responses to present day climate change. For this purpose, the use of palaeoenvironmental archives containing accurate information over large time intervals is a necessary condition for the development of solid observations and theories on Quaternary variations.

Among these archives, soils are a valuable reservoir of information, since they are strongly influenced by the processes tuning the environmental balance and can record their effects in the form of permanent features, recognisable and quantifiable using appropriate analytical methods (Cremaschi and Rodolfi 1991; Trombino, 1998). Unfortunately, the study of Holocene paleosols can be difficult since they are scarcely conserved in the present landscape, as a result both of the natural geomorphological evolution and of the intense human impact. It is therefore necessary to constantly search for new sites that can provide relevant results together with to investigate at a more detailed level the evidences already known.

The paleosols in the area of Mt Cusna (Northern Apennines, Italy) have provided in the last decades precious information about the natural and human influence on the landscape evolution of this area of the Northern Apennines during the Holocene. The area has been investigated since the Seventies, mainly as an archaeological proxy. In fact, this area features several mesolithic-neolithic sites (Castelletti and Cremaschi, 1975; Castelletti et al., 1976; Biagi et al., 1980), of which Mt. Bagioletto is probably the most representative (Cremaschi et al., 1984). In these studies, the human presence was investigated inside its paleoenvironmental context through a series of methods such as paleopedological surveys, soil micromorphology and palinological analyses. These studies, although accurate, were usually limited to the single archeological site. A more widespread approach was used in successive geomorphological studies (Panizza et al., 1982), in which a series of aspects (mainly climate, lithology, hydrology, geomorphology, geopedology) were involved in giving a comprehensive description of a large portion of territory. Unfortunately, such studies covered this area only partially, excluding large portions of it from their considerations.

In the last decade the main interest shifted on climatic and environmental aspects, with a focus on describing soil evolution combined with treeline fluctuations during the Holocene. The most recent studies aimed to investigate different proxy data from paleosols and other archives through a multidisciplinary approach: routine soil analyses were associated to a wide array of disciplines (dendrochronology, pedoanthracology, soil macro-remains, entomology) in order to define a more detailed history of Holocene climatic fluctuations (Compostella et al., 2012). Soil micromorphological approach was also intensified as a valid high resolution tool to investigate soil features and processes (Mariani, 2011).

These studies were successful in giving an accurate synthetic model for the interpretation of Quaternary environmental changes, but in doing so uncovered a new series of topics still to be properly addressed.

First of all, progresses made in the reconstruction of palaeoenvironmental change from different soil features have left behind many gaps in the knowledge of the geomorphic processes connected to the formation of the soils themselves. A full comprehension of the dynamics shaping the landscape in the present and past time would be needed to outline the spatial and temporal relationships occurring between landforms and climate and to understand the geomorphic response to variations in the environmental context. More detailed observations on the evolution of landforms would also be an important tool to investigate and explain soil diversity in the area. Moreover, this subject could be expanded to new areas, in order to widen the outlook of palaeoenvironmental studies to different conditions and potential new sources for proxy data.

On the other hand, a comprehensive characterisation of the soils in the area is also important. In fact, in a ristrected area where paleosols represent the main source of palaeoenvironmental and geoarchaeological proxy data, none of the studies already conducted ever focused on describing and explaining in detail soil nature and spatiotemporal relationships from a geopedological point of view. Again, this is connected to soil diversity: in this case not as a tool in support of paleoenvironmental reconstructions, but as an analytical approach in which pedogenetic processes are the main research topic. In fact, studies on soil formation in high mountain environments are scarce and related mainly to different geographical, geological and temporal contexts (e.g. Righi et al., 1999; Egli et al., 2001; Scarciglia et al., 2005; Mavris et al., 2012). It is interesting then to highlight soil formation processes in his area to provide a contribute in this field from a distinct set of conditions and to detect similarities and differences with pedogenesis in other sites.

To achieve this goal, two parallel approaches are needed. The first consists in the investigation of the soils in neighbouring areas in order to obtain a better framework on the general aspects related to soil formation. The possible inclusion of new pedogenetic processes from different contexts could both bring a larger scale view of pedogenesis and at the same time provide further useful data in the understanding of the framework of environmental change during the Holocene. This effort in soil survey should be coupled with an extensive geomorphological survey whose purpose, as stated before, is to produce a spatial and temporal frame over which soil data and paleoenvironmental considerations can be organised and compared.

The second approach relies on the application of new analytical methods used in different fields (agronomy, soil chemistry, paleopedology) on previously and newly investigated soil profiles: its main purpose consists in supplying better detailed information on known features and processes and in possibly discovering new aspects of soil formation and history before undetected.

Aim of this work is therefore to conduct an investigation on the soils, paleosols and landforms of the larger area of Mt Cusna ridge in order to define the relationship between geomorphic evolution and soil development, characterise the main pedogenetic factors acting on soils and landscape in past and present times and provide new information to help in the understanding of Holocene climatic variations.

This is achieved with the help of different tools. A detailed survey of landforms was conducted in order to recognise the different geomorphic processes and their relative importance and expression in different areas. The data obtained from this survey were organised in the production of a large scale geomorphological map which was used as the general framework in which to organise observations form soils and paleosols. A parallel survey and sampling of soils was carried out in known and new areas with the purpose of outlining the general characteristics of the soils and searching for new paleosols and other potential proxy archives.

The analysis of the identified soil profiles took advantage of multiple laboratory and microscope techniques to provide both maximum accuracy of the data and a wider overview of the aspects involved, with the help of additional analytical methods never used before in this area. The most representative paleosols known from previous studies were also resampled and subjected to new analyses in order to obtain a more detailed and comprehensive range of information on the formation and history of these soils.

Chapter 2

Overview of the study area

2.1 - Geography

The study area is located in the territory of Febbio in the Northern Apennines, inside the "Parco Nazionale dell'Appennino Tosco-Emiliano" (Tuscan-Emilian Apennine National Park). The area is delimited north by Mt Cisa (1698 m) and the N slope of Mt Bagioletto (1753 m), east by the town of Febbio, west and southwest by the Ozola stream and south by the Alpe di Vallestrina (1904 m) and the Lama Lite pass (1781 m). The most important landmark inside this area is Mt. Cusna (2121 m), second highest peak of the Northern Apennines. Other relevant peaks are Sasso del Morto (2010 m) and Mt. La Piella (2069 m). These three peaks belong to a continuous ridge oriented northwest to southeast. This area belongs to the Secchia river catchment area. Other reference points, outside this area, are the cities of Ligonchio to the west and Castelnuovo ne' Monti to the north, Mt. Prampa (1698 m) to the northeast, Mt Ventasso (1727 m) and the Pietra di Bismantova (1047 m) to the north, Alpe di Succiso (2017 m), the Cerreto pass (1261 m) and Mt La Nuda (1895 m) to the west, Mt Prado (2054 m) to the south. The highest peak of the Northern Apennines, Mt Cimone (2165 m) is located to the southeast, about 25 km away (fig. 2.1).

2.2 - Geology

The Northern Apennines originated during the Late Cretaceous to Present convergence between the European and Africa plates (Boccaletti et al., 1971; Kligfield, 1979; Vai and Martini, 2001). They currently extend from NW to SE bearing a vergence towards NE between two major tectonic features represented by the Sestri-Voltaggio line in the north and the Ancona-Anzio line in the south. Both features are interpreted as large structures with a large transcurrent component.

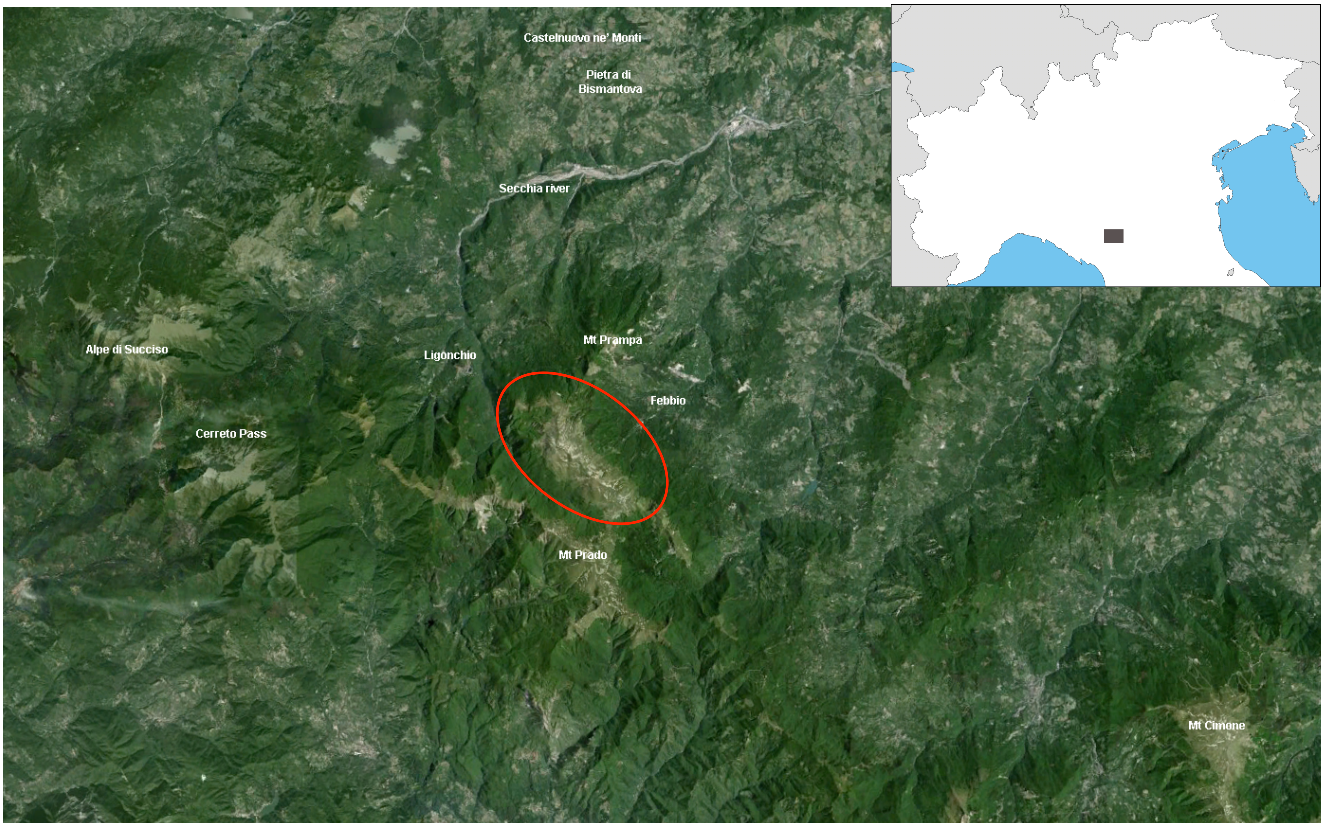

Fig. 2.1 - Overview of the study area (in red circle).

The overall structural framework results from the middle Eocene-Pliocene thrusting of oceanic and continental allochthonous units (Ligurian and Subligurian units overlain by the Epiligurian wedge-top Succession) over Oligocene-Miocene foredeep turbidite units (Ricci Lucchi, 1986; Pini, 1999). These units have been displaced even hundreds of kilometers from their point of origin (Bortolotti, 1992). The study area can be fully framed within the Tuscan Domain, characterized by a Triassic basal clastic section, first continental and then of shallow sea (not outcropping in the Reggian Apennines), followed in succession by evaporite deposits, by Jurassic carbonate platform deposits and by pelagic limestone and siliceous sediments, then by a terrigenous Cretaceous clay-carbonate deposition and by debris with the beginning stages of tectonic compression; Oligocene begins with the deposition of turbiditic siliciclastic sediments (Bortolotti, 1992). From the early Miocene, the orogenic wedge was affected by widespread thrusting and folding, as well as extensional tectonics (e.g., Carlini et al 2013, Clemenzi et al 2014). Since the late Miocene-late Pliocene its western part was subjected to a progressive exhumation process (Balestrieri et al., 2003, Fellin et al., 2007; Thomson et al., 2010; Carlini et al., 2013) which rate almost doubled during middle-late Pleistocene (Bartolini et al., 1982).

As for the detailed description of the Geological Units which characterise the study area (fig. 2.2), it is reported what is contained in the legend of the Emilia Romagna Geological Map 1:10000 (SGSS, 2007a, b, c, d):

Cervarola Succession (Tuscan Unit)

- Arenarie di Monte Cervarola (CEV): turbidite sandstones in thick layers alternating with pebbly sandstone and powerful deposits from slumping, passing at the top to sequences of thinner turbidites. Prevailing provenance from granitic-gneissic rocks. Turbiditic basin and basin margin deposit (Civago outcrops). Burdigalian.
- Arenarie di Monte Cervarola - Membro del Torrente Dardagna (CEV1): coarse turbidites in thick and very thick strata alternating with finer turbidites and with slumping levels even several meters thick, and pebbly sandstone. Thickness of about 800 m. Burdigalian.

Modino Succession (Tuscan Unit)

- Arenarie di Monte Modino (MOD): sandy-clayey turbidites, grey, in layers from thin to thick, consisting of a sandy matrix passing to pelite with A/P ratio ~ 1. Alternating packs of medium to thick strata consisting of medium or coarse sandstones with, in some places, few centimetres thick mudstones at the roof. Turbidites of mixed composition or calcarenitic/marly are rare. Bottom contact in alternations on MMA. Thickness of several hundreds of meters. Chattian - Aquitanian.
- Marne di Marmoreto (MMA): marls, grey silty marls with poorly visible stratification with rare interbedded siltstones and fine clear-grey sandstones, weathering to yellowish, also of volcaniclastic origin. In the basal part are interbedded clay and limestone breccias. Discordant bottom contact on FIU. Escarpment deposit. Maximum thickness of about 100 m. Rupelian - Chattian
- Litofacies a brecce del Rifugio Battisti (MMAa): coarse breccias mostly matrix-supported, metric or decametric thick, originated from debris flows sometimes coarsely stratified. Clay and limestone clasts, in sizes up to decimetric, of Ligurian-Subligurian origin. Present at the base of the Marmoreto Marlstones.
- Argille di Fiumalbo (FIU) in the lower part greenish or red Varicolori shales intercalated with thin calcarenitic/marly layers often gathered in thick decimetric sequences and with chondrites and fucoids bioturbation in the marl intervals. In the upper part-ash grey marl shales with interbedded siltstones and fine sandstones in thin layers. Discordant stratigraphic contact with the successions below. Maximum thickness of 200-300 m. Bartonian - Rupelian
- Argille di Fiumalbo - Membro del Rio Acquicciola (FIU2): calcareous cemented sandstones in sometimes thick layers. Intercalated in the upper part of the Fiumalbo Clays, perhaps in more levels. Maximum thickness of some tens of meters.
- Formazione dell'Abetina Reale (ABT): calcilutitic or grey calcareous matrix turbidites, passing to whitish calcareous marls, in thin to very thick layers, alternating with fine sandy and silty matrix turbidites and dark-grey clay roof in thin and average layers. Local interbedded layers of graded siliciclastic and ophiolitic sandstones. Inoceramus traces and remains. Turbidites of deep marine environment. Continuous passage to the formation below. Campanian sup.

- Argille Variegate con Calcari (AVC): brown and green clays, rarely Varicolori, with grey-brown limestone layers with reddish hue, graded siltstones and marl layers. Clay-limestone breccia with prevalent type "palombini" limestone clasts . Lead-grey clays with thin and average bluish-grey limestone layers. Deep marine environment deposit. Bottom tectonic contact with Sorba flysch, in neighbouring areas. Thickness up to about 200 m. Barremian? - Albian?
- Marne di Civago (CIV): ash grey marls, often silty, with poorly distinguishable stratification. Locally levels of black flint. Interbedded with thin discontinuous sandstone layers also from volcaniclastic origin, with coarse sand levels of marly matrix with abundant redeposited glauconite. Escarpment deposit. Discordant stratigraphic contact with the successions below. Thickness of 50-100 m. Aquitanian.
- Marne di Civago - Litofacies a brecce del Rio Rumale (CIVa): Coarse polygenic Breccia Horizons with mostly clay and limestone elements. Intercalated in the lower part of the Civago Marlstones. Aquitanian.
- Formazione di Serpiano - Membro dei Poggi di Fontanaluccia (SRP1): siliciclastic turbidite sandstones mostly silty with pelitic-marly interlayers, in thin and average layers. Levels of black flint in lists, especially frequent at the bottom. Aquitanian?
- Macigno (MAC): in the lower part sandy-clayey turbidites in thin layers (a few meters). In the middle part layers thick and very thick sandstone with coarse matrix and scarce mudstones. In the upper part of the succession plain-parallel turbidites (sometimes with calcarenitic bioclastic matrix and pelitic-marly roof) in medium and thick layers, alternating with thinner turbidites. Maximum thickness of about 1000 m. Chattian - Aquitanian.

Continental Quaternary deposits

- Active landslide deposit (a1): gravitational deposit with evidence of current or recent movements, consisting of heterogeneous, rarely monogenic, rock types of different size composition, more or less chaotic. The texture of the deposits is conditioned by the substrate lithology and type of prevailing movement. Most of the landslide deposits in the Apennine area are complex and the result of more types of movement superimposed in space and time (typically slides/flows). The prevalent texture is constituted by clasts of variable size immersed in an abundant clayey and/or sandy matrix.
- Quiescent landslide deposit (a2): gravitational deposit with no evidence of current or recent movements but with the possibility of reactivation, consisting of heterogeneous, rarely monogenic, rock types of different size composition, more or less chaotic. The texture of the deposits is conditioned by the substrate lithology and type of prevailing movement. Most of the landslide deposits in the Apennine area are complex and the result of more types of movement superimposed in space and time (typically slides/flows). The prevalent texture is constituted by clasts of variable size immersed in an abundant clayey and/or sandy matrix.

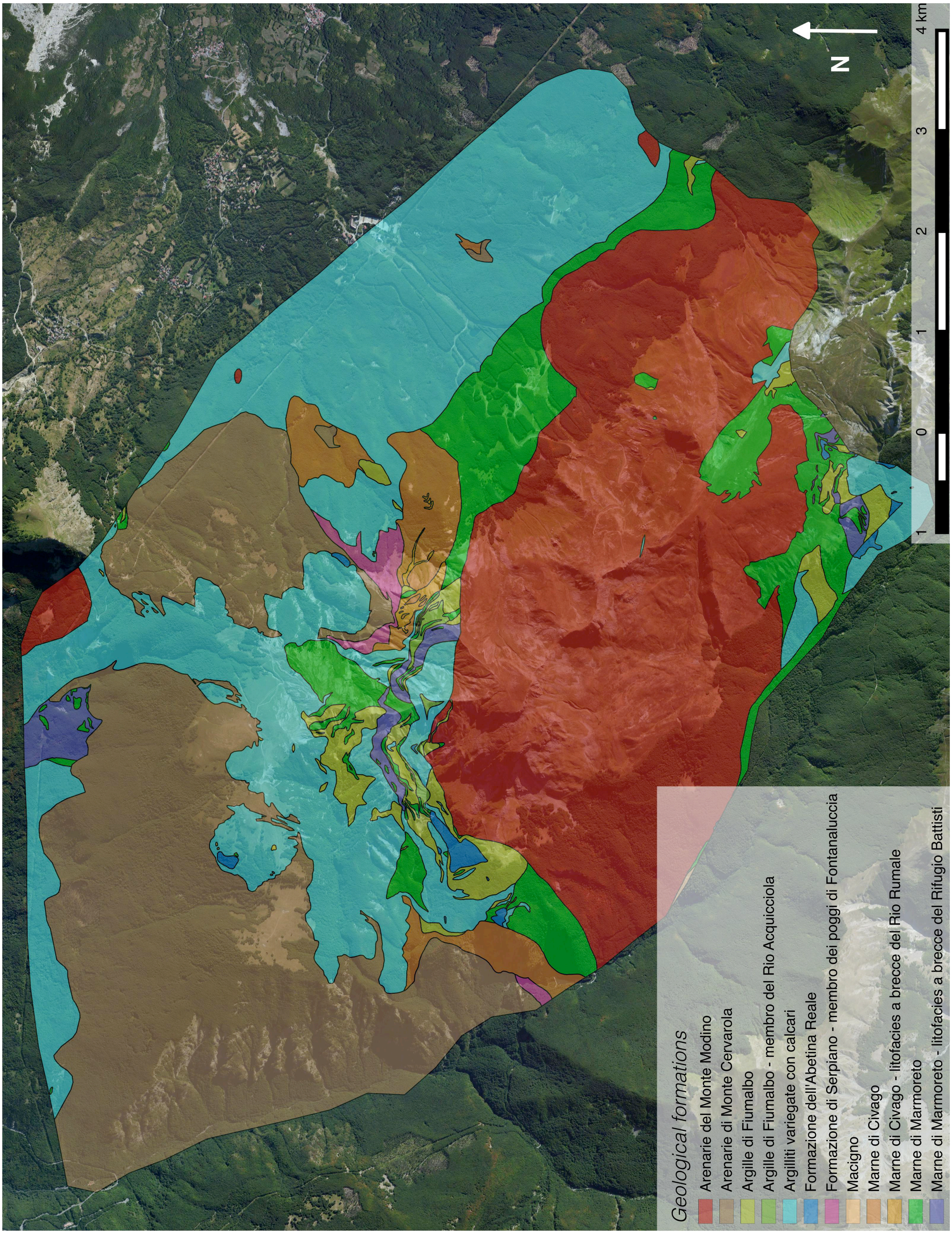

Fig. 2.2 - Geological formations in the area (SGSS, 2007 a, b, c, d).

- Fall/topple deposit (a1a, a2a): originated from detachment of rocks by a steep slope and put in place by free fall, bouncing and rolling of pebbles and boulders. The accumulation of debris consists of heterogeneous material of different size composition with lithoid fragments ranging in size from a few cm3 and dozens of m3, with no or sandy-pelitic matrix, in places weathered and pedogenized. It features sudden reactivation events and extreme speed of movement.
- Slide deposit (a1b, a2b): deposit originated from the movement towards the base of the slope of a mass of soil or rock, which occurs in large part along a rupture surface or within a band, relatively thin, of intense shear deformation .
- Flow deposit (a1d, a2d): put in place by a continuously distributed movement within the moving mass. The cutting surfaces within this mass are multiple, temporary and generally not preserved. The materials involved are mostly cohesive. The most frequent deposits consist mainly of a clayey and/or clayey-sandy matrix including clasts of varying sizes.
- Complex landslide deposit (a1g,a2g): put in place following a combination in space and time of two or more types of motion.
- Block slide deposit or DSGSD (deep-seated gravitational slope deformation) (a2h): complex and deep gravitational mass movement that affects large rock masses, sometimes with its related surface cover, and is conducted through a deformation mostly slow and progressive of the rock mass, without a well determinable sliding surface.
- Slope deposit S.L. (a3): deposit consisting of heterogeneous lithologies of different size composition, more or less chaotic. Frequently the deposit shows a texture formed by clasts of variable size immersed and supported by a clayey and/or sandy matrix (which can be weathered by oxidation and soil formation), in places stratified and/or cemented. The genesis can be tentatively gravitational, by surface runoff and/or solifluction.
- Eluvio-colluvial deposit (a4): blanket of debris, generally fine (sand, silt and clay) produced by "in situ" weathering or selected by the mixed action of runoff and gravity, with sometimes sharp-edged or slightly rounded clasts.
- Scree (a6): accumulation of debris consisting of heterogeneous material of different size composition, usually at high or very high altitudes, with lithoid fragments ranging in size from a few cm3 to dozens of m3, with no or sandy-clayey matrix weathered and pedogenized, of gravitational origin frequently at the foot of escarpments and along the steeper slopes.
- Evolving alluvial deposits (b1): gravels, sometimes imbricate, clayey sands and silts of fluvial origin, currently subject to variations due to fluvial dynamics; generally incoherent and chaotic debris, consisting of heterogeneous, sometimes rounded clasts of different size composition with sandy matrix, at the mouth of watersheds and secondary valleys.
- Skeletal spread moraine deposit (c3): incoherent detrital deposits in a chaotic structure made of materials of different size composition embedded in silty-sandy matrix. Locally frequent erratic blocks.

- Marsh deposit (f1): silts and deposits of organic material accommodated in depressions mostly of glacial origin.
- Evolving colluvial fan (i1): alluvial deposits, mostly fan-shaped gravel open towards the valley, at the mouth of valleys transversal to the main waterways where slope decrease causes sedimentation of the material transported by water, subject to evolution with the water dynamics.
- Inactive colluvial fan (i2): alluvial deposits, mostly fan-shaped gravel open towards the valley, at the mouth of valleys transversal to the main waterways where slope decrease causes sedimentation of the material transported by water, not currently subject to evolution.

2.3 - Geomorphology

The study area is modelled by glacial and periglacial processes which acted in the past, while slope and fluvial processes acted with a stronger influence in more recent times together with human activity (Panizza et al., 1982). The glacial process is also the one related only to the past: the slopes of Mt. Cusna were diffusely subject to glacial activity during the last glacial period (Losacco, 1949), with the formation of various cirques on the Northeastern slopes between 2100 and 1900 m. These have been strongly remodelled by recent erosive phenomena, but their shape and dimensions can still be reconstructed. Another effect of glacial activity during the last glacial phase is the deposition of wide till deposits. It has been argued that the lowest and biggest glacial tongues reached between 850 and 900 of elevation and where related to the Last Glacial Maximum (Panizza et al., 1982); other successive events where also consequently related to later periods. A second generation of moraine arcs, located around 1100-1300 m a.s.l. was associated to the Pleniglacial, while a third at 1400-1600 m a.s.l., to the Tardiglacial.

Periglacial morphologies are numerous in variety and quantity. A great part of the gentle morphology of this area is probably the consequence of the great influence of Periglacial activity which allowed the formation of great quantities of debris through gelifraction from such erodible rocks. This debris, mobilised by slope movements (gelifluction and flows) and the action of water, has during time covered the roughness of the landscape. In the Febbio area have also been found glacis deposits, nivation hollows, stratified debris (éboulis ordonnés, deposits composed by ordered strata of angular gravel obtained by gelifraction and put into place by gelifluction or snowmelt action - also called grèzes litées - Castiglioni, 1986), and rock glaciers. Gelifluction phenomena are regaining strength in recent times thanks to the deforestation produced by human activity leaving barren soils better available to frost activity during the winter (Panizza et al., 1982).

Slope processes are, however, spread evenly throughout the study area; thanks to the great heterogeneity of rocks present, the whole area is subject to a varied modelling of the slopes, ranging from slightly inclined slopes on clay materials, to cliffs modeled in calcareous sandstone. All slopes are affected by landslides of different nature and size (Panizza et al., 1982). At higher altitudes can be found a deposit of atypical extension, which form could be related to a series of widespread slow movements occurring during the Lunigiana earthquake of 1920.

Stream erosion phenomena get relevant during the Holocene when the glacial retreat and, later on, disappearance and the formation of a vegetation cover reduced the sediment yield of running waters, which passed from depositional to erosive behaviour. This change caused an intense incision of the slopes, testified by steep erosional cliffs and gorges or by forms of solifluction and flows on less steep areas or even by badlands. Many of these phenomena are presently active and the human impact only gave them more force through forest clearing which progressively left ample portions of territory without a sufficient forest cover to prevent soil erosion (Panizza et al., 1982).

As a testimony of stages of slope instability is the presence in the study area of a relict surface, the paleosurface of Mount Cusna (Panizza et al., 1982), currently buried by a considerable colluvial layer of different thickness. This paleosurface extends from the top of Mount Cusna, N along the side to Mount Bagioletto, to E up to Prati di Sara and W toward the Rio Grande (Bernini et al., 1978). Currently this surface is in active erosion: in fact water incision has fragmented it in different strips, and lateral erosion has conferred to its sides a particular concavity between the maximum limit of the roots and the horizon B of buried soil (Panizza et al., 1982). Present conservation of these strips is mainly due to the restraining work of the grassland and shrub vegetation root systems.

2.4 - Soils

Panizza et al. (1982), studied and described some profiles in the area giving a broad characterisation and using Soil Taxonomy (Soil Survey Staff, 1975) as reference. They established three altitudinal belts characterised by the interaction of several factors such as substrate and soil temperature regime. Soil moisture regime is not considered among these factors since it is mainly characterised as udic (dry for more than 90 or 45 consecutive days in total in normal years) and does not change among the different altitudinal belts. The three altitudinal belts can be described in this way as follows:

Below 1300 m mean annual temperature is between 8°C and 15°C, with a mean difference in summer and winter of more than 6°C (mesic temperature regime). The strong presence of partially dynamic clays, inherited from the parent material, and the high content of carbonates cause soil cracking, which in slope topography results in a continuous rejuvenation by erosion. Soil formation is recent and forms Entisols and Inceptisols; locally, in areas where clays produce areas less permeable to water, soils with hydromorphic features are found.

Between 1300 and 1900 m the temperature regime becomes frigid, with temperatures between 0°C and 8°C. This altitudinal band is affected by the majority of degradation processes, leaving substantial amounts of material. For that reason, Inceptisols developed on colluvial deposits are frequent. Beneath these deposits are traces of older soil formation, in the form of relict or buried paleosols; the most important are associated to the paleosurface located on the northern slope of Mount Cusna (Panizza et al., 1982).

Above 1900 m temperature regime is cryic (similar to frigid, but with a more limited mean summer temperature). The substrate is composed primarily by sandstone and on average more draining. This increases greatly organic matter and acidity, which in combination tend to form Spodosols. The most common type of soil is though Entisols, since the harsh climate heavily impairs soil formation.

2.5 - Climate

Different meteorological stations can be taken as reference for the area in exam. These stations are scattered inside the Reggiano and Modenese Apennines (fig. 2.3). The nearest is located in Ligonchio, at a lower quota compared to the area of study (928 m). Observing the climograph it can be recognised the typical Apennine rainfall regime, with a maximum of rainfall in November and a well marked minimum in July, though without the incurrence of dry conditions. Mean rainfall is quite abundant with valuer averaging 2000 mm per year. There are no significant variation to this regime at slightly higher elevations, as indicated by temperature and precipitation records in the Ozola station (1220 m), the other nearest station available.

The station which can best represent climatic conditions on the Mt. Cusna ridge though is the Mt. Cimone one (2165 m), 50 m higher than Mt. Cusna. Here the recorded mean annual temperature is of 2.2°C with a February minimum (-4.6°C) and an August maximum (10.6°C). Rain is distributed quite irregularly during the year, with low values (783 mm) due both to its quota and its geographic position. Compared to Mt. Cusna and in general to the part of the chain NW to it, Mt. Cimone is less

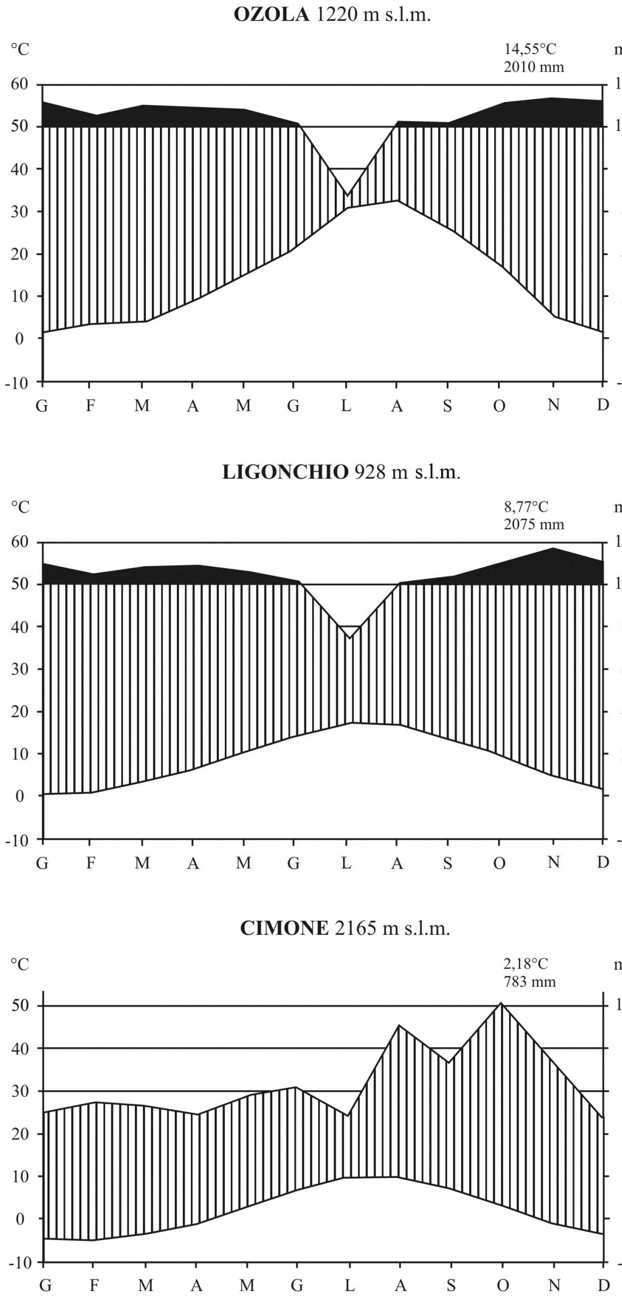

Fig. 2.3 - Climographs related to the study area. Stations of Ozola, Ligonchio and Cimone are reported.

subject to the influence of the Tyrrhenian Sea and the moist air currents coming from it: this implies less rainfall, determining a subcontinental climate regime (Bertolani Marchetti et al., 1994; Tomaselli, 1994; Tomaselli et al., 1994).

2.6 - Vegetation

The northern Apennines stand on the southern limit of the medioeuropean phytogeographical zone in contact with the mediterranean phytogeographical zone (Pignatti, 1979). In its highest part it can be divided in a series of vegetation planes. Recent studies have produced a vegetation map of the northern area of Mt Cusna (Redondi, 2009)

The montane horizon is located between 800-1000 m and 1600-1750 m. this is occupied prevalently by beech (*Fagus sylvatica*) forests. The ample distribution of beech gives an appearant uniformity to these forests even if in this part of the Apennines are present different types of beech forest (Tomaselli, 1997). In particular in the area of study we find a vegetation dominated by *Fagus sylvatica*, monospecific in the tree zone, with an undergrowth composed by species such as *Vaccinium myrtillus, Luzula nivea, Hieracium sylvaticum, Oxalis acetosella, Saxifraga rotundifolia, Solidago virgaurea, Myosotys sylvestris* and *Galium odoratum* (Redondi, 2009). Nearest to the tree line, here at 1730 m, the beech forest ends and and opens in patches, also present at lower elevations, in which the tree cover is composed by *Fagus sylvatica* (which gets sparse and contorted going up), and *Sorbus aucuparia* (typical element of the high part of beech formations). In some areas a low heathland develops, dominated by *Juniperus nana*, and characterised by sparse *Laburnum alpinum* trees, which is a rare species in the Apennines (Redondi, 2009).

Above the natural tree line up to 1800-1900 m can be found a heathland plane with a prevalence of *Vaccinium myrtillus* and *V. gaultherioides*. *V. vitis-idaea* is not always present. Two varieties of *Vaccinium* heathland can be recognised (Tomaselli, 1997): one with the presence of *Empetrum hermaphrodithum* and a high cover and frequency of *V. gaultherioides*, more related to steeper slopes and convex forms of relief where the snow cover stays no more than six months per year (Rossi, 1989). The variety with *Hypericum richeri* is the instead are characterised by the predominance of *V. myrtillus*, by the absence of *Empetrum* and by stronger importance of grassland species (associated with those can be found species of *Nardus stricta* dominated pastures such as *Avenella flexuosa, Hypericum richeri, Carex sempervirens, Meum athamanticum, Geum montanum, Festuca nigrescens, Luzula gr. sylvatica, Leontodon helveticus, Homogyne alpina, Anthoxanthum alpinum*; Redondi, 2009). It stares on more gentle slopes and on concave morphologies which permit the snow to stay for more than six months of the year.

From 1800-1900 m to around 2000 m dominance goes to high-altitude grasslands which can be differentiated by substrate typology. Neutrophilous and calcicole grasslands are developed on soils on marlstones or limestones, and can be divided in terrace vegetations with *Anemone narcissiflora* and *Aquilegia alpina* and in pastures with *Festuca puccinellii* and *Trifolium thalii*. The latter on slope screes steeper then 35°, is characterised by discontinuous vegetation with *T. thalii, Alchemilla alpina, A. saxatilis* and *Cirsium bertolonii* (Tomaselli, 1997). Primary acidic grasslands are typical of sandstone and claystone. They are characterised by *Trifolium alpinum, Plantago alpina, Silene acaulis, Luzula spicata*. On the steepest slopes exposed to SW another grassland type appears which has as dominant species *Festuca robustifolia*, an Apennine endemism (Tomaselli, 1997). Secondary acidic grasslands (pasture associations) are the most diffused grassland in the area of study. They can be divided into two types. One is dominated by *Nardus stricta*, which is an index of pasture degradation, and are characterised by the presence of species such as *Geum montanum, Potentilla aurea, Gentiana kochiana, Leontodon helveticus, Centaurea nervosa, Festuca nigrescens, Antennaria dioica, Luzula multiflora, Potentilla erecta* (Tomaselli, 1997). *Brachypodium genuense* dominated grasslands and to developing correspondence of the steepest slopes exposed south. They also have a dryer microclimate and a quite heterogeneous floristic composition. *Brachypodium genuense* itself is an Apennine endemism (Tomaselli, 1997). This grasslands tend to evolve with time into *Vaccinium* heathland, but exposition to south, slope steepness and pasture activity can stop or anyway slow this process (Tomaselli, 1997).

2.7 - Human presence

The first traces of human presence in this area of the Apennine goes back to the Mesolithic. Several sites have been found which showed the frequent passage of communities of hunters and gatherers between the Boreal and the beginning of the Atlantic period (Castelletti and Cremaschi, 1975). In particular, in the study area are present the two sites of Bagioletto and Lama Lite in which have been found both lithic artefacts and traces of fireplaces, together with the remains of campsite structures (Castelletti et al., 1976; Panizza et al., 1982; Cremaschi et al., 1984). Later on, only scattered frequentation traces have been found, indicated by remains from the late Iron Age and Roman Age (Panizza et al., 1982; Cremaschi et al., 1984); from the Subatlantic period onwards there is a gradual return towards a more intense exploitation of the forest (Castelletti et al., 1976). Historical sources show progressive colonisation of the area from the High Mediaeval Times, with communities surviving on livestock and forest exploitation. Agriculture plays a minor role and is limited to small patches nearest to settled villages (Panizza et al., 1982). It is in this phase that human impact, above all the forest use, could ever had an important role in increasing slope instability by erasing the tree cover and favouring colluvial deposition in the study area.

In present times farming grows up to 1000-1300 meters, while pasture reaches even greater heights. In addition to these activities forested areas have been destroyed to derive ski slopes and parking for tourist activities.

Chapter 3

Materials and methods

3.1 - Geomorphological and soil survey

Field survey was carried out from 2013 to 2015, and was divided into three field seasons, one for each summer period. Preparation of the geomorphological map (attachment n.1) was done from resources from Panizza et al. (1982) and SGSS (2007a, b, c, d). The last year was dedicated to verifications of the drawn map. Soil survey was conducted in steps. During the 2013 and 2014 field seasons a thorough work of description and sampling of soils was conducted in order to obtain a uniform picture of pedogenesis in the area. A total of 73 soils was described in the field (see attachment n.1). The focus was especially pointed in two directions: the first was aimed at covering the portions which had never been investigated before with as much detail as possible. The second involved a detailed work of re-description and re-sampling of a series of soils partly published during previous investigations (Panizza et al., 1982; Cremaschi et al., 1984; Compostella, 2011; Compostella et al., 2012) and partly in the form of material already available but yet to be studied. This was done in order to run further analyses on those soils and to maintain the necessary uniformity of data.

3.2 - Soil field description and sampling

The soils studied were all thoroughly described at the time of the opening of the profiles. The full section of the soil was observed, from field surface down to, where possible, the parent material at the base of the profile (Sanesi, 1977; Persicani, 1989; Cremaschi and Rodolfi, 1991; McRae, 1991; Sanesi, 2000). In none of the studied sites it was necessary to go beyond a depth of 2 m, thus remaining within the limits set by Soil Taxonomy (Soil Survey Staff, 2014).

3.2.1 - Field description

For each station were reported:

- location and elevation (acquisition of coordinates using GPS)
- slope and aspect of the relief
- substrate nature (lithology of the parent material by literature or direct observation)
- land use and vegetation
- surface features (outcroppings and coarse surface fragments, erosion, morphological environment, section type, etc.)

For each profile were reported:

- soil depth
- soil type (simple or compound)
- a listing of every soil horizons
- A name was assigned to each horizon (provisional, subsequently modifiable according to the results of laboratory analysis and microscope observation) and were recorded:
- thickness and boundary depth (with distinctness and topography)
- moisture
- colour (according to Munsell Soil Color Charts: Munsell® Color, 1994)
- textural class of the fine earth fraction
- size, shape, frequency, and lithology of the coarse fraction
- size, shape and resistance of aggregates
- size and frequency of pores and roots
- possible presence of pedofeatures (clay coatings, nodules, mottles, etc.)

3.2.2 - Soil sampling

Soil sampling was conducted with different methodologies, depending on whether or not they were samples for laboratory analyses, or undisturbed samples for the preparation of thin sections. In the first case, it was collected a homogeneous and representative sample for each horizon identified in the field, variable in weight between 0.5 and 1 kg; if case of considerably thick horizons several samples were taken at different depths in order to highlight any differences invisible to the naked eye (Ministero per le Politiche Agricole, 1999). Sampling was always performed from the bottom to the top of the profile in order to avoid polluting the underlying horizons still to be sampled (Cremaschi and Rodolfi, 1991; Giordano, 1999).

With regard to sampling for micro-morphological analysis, the use of Kubiena boxes allowed to take samples of undisturbed soil. Kubiena boxes are appropriate metal containers with removable lid and bottom which allow to extract and transport undisturbed soil samples; they are inserted in the profile and once extracted retain inside them a prism of undisturbed soil. On each Kubiena box was reported the original orientation of the sample, information needed in order to properly interpret the information derived from the observation of the corresponding thin section (Kubiena, 1953, Stoops, 2003).

3.2.3 - Laboratory pre-treatments

All samples taken in the field have undergone a series of pretreatments before being subjected to the subsequent analysis. They were dried, weighed and sieved with a sieve with a square mesh of 2 mm, to separate the coarse fraction (retained in the sieve) from the fine earth. The coarse fraction was then thoroughly washed and weighed. Its weight was then expressed as a ratio to the total weight of the sample. The fine earth was used instead to perform all subsequent chemical, mineralogical and physical analyses (Avery and Bascomb, 1974; Gale and Hoare, 1991; Ministero per le Politiche Agricole, 1999).

3.3 - Particle size distribution

The particle size distribution of a soil is the distribution of its mineral particles into size classes; It is a fundamental property on which depend many other chemical and physical properties of soils, and its determination is the basis of a correct classification of a soil (Ministero per le Politiche Agricole, 1999). Knowing the particle size, it is then possible to derive the texture of the sample, i.e. the proportion of the constituents of the earth end of the soil, grouped into size classes (McRae, 1991).

For particle size analysis it was used the fine earth fraction in quantities of about 100 g. The portion to be subjected to analysis was obtained by one or more subsequent quartering, so arranged that the sub-sample was representative of the original sample. The obtained fraction was weighed and then pre-treated with hydrogen peroxide (H_2O_2, 130 volumes) in order to destroy organic matter, which, by favouring aggregate formation, interferes with the analysis.

Each sample was then analysed using two distinct methodologies applied to different granulometric fractions: the distribution of sand (particles of diameter varying between 2 mm and 63 µm) was determined by sieving, the distribution of silt (particles of diameter varying 63 and 2 µm) was determined by the Casagrande aerometer method (Avery and Bascomb, 1974; Gale and Hoare, 1991); the amount of clay was deduced by subtracting the sands and silts to the initial weight of the sample.

Sand sieving was conducted on both wet and dry samples, using a column of 10 mesh sieves with decreasing values (1400, 1000, 710, 500, 355, 250, 180, 125, 90 and 63 µm). For the wet sieving it was used a stirrer under a constant stream of water to favour particle passage through the sieve; for dry sieving was used an intermittent mechanical stirrer, operated for 20 minutes. The sieves were then weighed in order to obtain the amount of sand fraction for every class.

The fraction of the sample passing through the 63 µm sieve was collected in water tanks and left to settle for at least 24 hours; the volume of water has been progressively reduced by siphoning to obtain a total volume smaller than 1000 ml. The material thus obtained was analysed by aerometry with the method of the Casagrande aerometer, into columns of 2 l volume after treatment with calgon (i.e. 3 g of sodium hexametaphosphate for each column). The aerometric analysis exploits Stokes law according to which settling velocity of a particle is proportional to its size. Density of the suspension thus tends to decrease with the passage of time and its variation depends on the size of the particles contained in the column. The measurement of density and temperature at standard intervals over 24 hours allows therefore to establish the amount of silt present in the sample.

The data obtained by sieving and aerometry are then unified into frequency cumulative curves that allow an effective visualisation of the distribution of the constituents of the soil into dimensional classes.

3.4 - pH

The pH was determined in water, using the sample sieved to 2 mm. Three different measure were performed:

- Soil-water
- Soil-KCl solution
- Soil-NaF solution, applied only to selected profiles in order to assess the presence of andic properties, according to FAO (2014).

In all cases 10 g of soil were added to 25 ml of solution (proportion soil/solution of 1/2.5); the suspension was placed on a shaker for twenty minutes and then left to stand for 24 hours. The pH measurement was carried out through the use of a dual point calibration automatic tester. In the case of NaF solution measurement was carried out 30 seconds after further stirring. The results were expressed as pH units to one decimal place.

3.5 - Organic carbon

Organic carbon determination was obtained through the standard method by Walkley and Black (1934), which uses the reduction of potassium dichromate $K_2Cr_2O_7$ excess by organic matter and the subsequent determination of the remaining $K_2Cr_2O_7$ by oxide-reductive titration iron with a solution of iron ammonium sulphate. The quantity of sample subjected to testing was always particularly low (approximately 0.250 g), given the high quantity of organic carbon content in the soils studied (the amount of sample must be such as to ensure that, at the end of the reaction, at least 3 ml of $K_2Cr_2O_7$ remain in excess). The procedure is as follows:

1. the organic matter is oxidized with 10 ml of $K_2Cr_2O_7$ and 20 ml of sulfuric acid (H_2SO_4). It is left to react inside a covered flask for 30 minutes.
2. 200 ml of water are added thus stopping the reaction. Then 5 ml of H_3PO_4 acid and 0.5 ml of acid 4-diphenilaminsulphonate sodium ($C_{12}H_{10}NaNO_3$) are added.

3. The excess dichromate is titrated by the solution of ferric ammonium sulphate (Mohr salts) $Fe(NH_4)_2(SO_4)_2 \times 6H_2O$. The titration is carried out on a magnetic stirrer.

The organic carbon content is expressed in g/kg without decimals; to obtain the corresponding value of organic matter starting from the organic carbon content was used a multiplication factor equal to 1.724 (Astori et al., 1994; Ministero per le Politiche Agricole, 1999).

3.6 - Exchangeable bases and cation exchange capacity (CEC)

The method used for the determination of cation exchange capacity is through the use of barium chloride and triethanolamine. 2 g of soil sample sieved to 2 mm are monosaturated with barium for repeated treatment with a solution of barium chloride at pH 8.2. Subsequently the Ba-saturated sample is washed for several times with a defined quantity of a solution of magnesium sulfate. The reaction leads to the formation of insoluble barium sulfate and, therefore, to the full exchange of Ba/Mg. The excess of magnesium in solution is determined by complexometric titration with EDTA. Cation exchange capacity corresponds to the amount of magnesium adsorbed calculated by difference. The solution from the Ba-saturated sample is used to measure the amount of exchange cations present (K^+, Na^+, Ca^{++}, Mg^{++}).

Exchangeable bases are expressed in mg/kg, the cationic exchange capacity in $cmol^+/kg$. From these it is possible to calculate base-cation saturation ratio (BCSR) using the formula:

$([Ca^{++}] + [Mg^{++}] + [K^+] + [Na^+]) *100 / CEC$

3.7 - Iron extractions

3.7.1 - Total iron

The total content of iron of the soil sample is extracted by digestion with a mixture of hydrochloric, nitric, hydrofluoric and perchloric acid. After sieving of the sample with a mesh of 0.5 mm, 1 g is weighed and placed into a teflon vessel, 2 ml of hydrochloric acid, 2 ml of hydrofluoric acid and 5 ml of nitric acid are added. The vessel is put into a MILESTONE microwave system and treated for 40 minutes. 4 ml of hydrofluoric acid and 6 ml of perchloric acid are then added and the resulting solution is then heated until almost total evaporation. The reading of the amount of solubilized iron in the remaining solution is determined by means of a ICP-ES (model JY24 of Jobin-Yvon), after the appropriate dilutions.

3.7.2 - Iron extractable in ammonium oxalate acid

This method is used to determine the oxalate-extractable iron, corresponding to amorphous or poorly crystalline iron oxides. The ammonium oxalate acid solubilises the amorphous iron oxides through a mechanism of complexation. High stability of the Fe-oxalate complexes causes the reagent to bring in solution also the iron linked to the organic substance. Shaking needs to be carried out in the dark to avoid photo-degradation of the complex.

After sieving of the sample with a mesh of 0.5 mm, 1 g is weighed and placed in a 50 ml tube, 40 ml of ammonium oxalate are added and this solution is shaken on a mechanical shaker for 2-3 hours in the dark. The reading of the amount of solubilized iron in the supernatant is determined by means of a ICP-ES (model JY24 of Jobin-Yvon), after the appropriate dilutions.

3.7.3 - Iron extractable in dithionite-citrate-bicarbonate.

This method, with steps similar to the above, is used for the determination of iron extractable in a solution of sodium dithionite and sodium citrate, corresponding to free iron oxides (amorphous and crystalline). The method is based on solubilisation of the iron oxides by the combined action of a reductant of Fe (III) and a complexing of Fe (II) and Fe (III). Bicarbonate is employed to buffer the solution.

After sieving of the sample with a mesh of 0.5 mm, 1 g is weighed and placed in a 50 ml tube, 40 ml of ammonium oxalate are added and this solution is shaken on a mechanical shaker for 16 hours in cell thermostated at 25°C. The reading of the amount of solubilized iron in the supernatant is determined by means of a ICP-ES (model JY24 of Jobin-Yvon), after the appropriate dilutions.

3.7.4 - Iron indices

In order to compare the results of the iron extractions to the soil characteristics, the following indices have been calculated: the ratio between free and total iron (Fe_d/Fe_{tot}), the amorphous/free iron ratio (Fe_o/Fe_d) and the weathering index ($(Fe_d-Fe_o)/Fe_{tot}$), which expresses the fraction of crystalline free iron to total iron. These indices are the mainly used in literature to compare the different iron oxide forms (e.g.: Dormaar and Lutwick, 1983; Costantini et al., 2006; Mahaney and Hancock, 2014).

3.8 - Total nitrogen (Kjeldahl method).

In the method used the whole soil sample is mineralised with boiling sulphuric acid (H_2SO_4), 98% concentrated, after the addition potassium sulphate, which elevates the boiling temperature of the acid, and a mixture of selenium and copper sulphate as catalyst. After mineralization, the solution is rendered alkaline and then distilled. The distilled ammonia is quantitatively collected on a diluted solution of boric acid and titrated with sulphuric acid.

After sieving of the sample with a mesh of 0.5 mm, 1 g is weighed and placed in a glass tube, 20 ml of sulfuric acid and selenium and copper oxide are added and brought to boiling. The mineralization is conducted inside a digester until the liquid is clear (about 1 hour). At the end it is allowed to cool for about 20 minutes, then diluted, and alkalised with 40% NaOH. The ammonia is then distilled for about 5 minutes and collected in 10 ml solution of 1% boric acid containing 6 drops of indicator (methyl red and bromocresol green). After all the ammonia has been distilled, the solution is titrated with 0.01N sulfuric acid.

3.9 - Available phosphorus (Olsen method).

This method consists in the extraction of phosphorus with 0.5 M sodium bicarbonate buffered at pH 8.5. The extracted phosphorus is dosed by spectrophotometry of the blue complex obtained by reduction of the acid phosphomolybdic.

After sieving of the sample with a mesh of 0.5 mm, 2.5 g is weighed and placed in a polyethylene bottle of 125 ml with 50 ml of extracting solution. The mixture is stirred on a mechanical shaker for 30 minutes and centrifuged for 5 minutes at 3000 revolutions/min. 10 ml of the clarified extract are collected and transfered into 50 ml graduated flask slowly adding 2 ml of 1N sulphuric acid to bring pH to 5±0.1. 5 ml of ascorbic acid and distilled water are added to bring to volume. The mixture is stirred with caution and is measured at 650 nm after leaving to stand at room temperature for about 15 minutes. The measures must be carried out within 2 hours.

Finally, to express the value of phosphorus as P_2O_5 used in international agricultural, multiply the value obtained previously for 2.2915. The expression is in mg/kg.

3.10 - Clay mineralogy

Samples of clays below 2 μm were extracted from soils for mineralogical analyses. Samples were treated with hydrogen peroxide at 40 volumes for 1 day, than diluted with deionised water and put into columns of 0,5 l volume after treatment with calgon (i.e. 3 g of sodium hexametaphosphate for each column). After being left to settle for 8 hours an appropriate volume of liquid was taken from the top of the column according to Stokes law, and the suspension treated with magnesium chloride in order to allow flocculation of clay. Samples were then dried, powdered and inserted into glass capillary for measurements. For parent material comparison, the least weathered gravel clasts were sampled from the lowermost horizons of each profile, powdered and inserted into glass capillary.

X-ray Powder Diffractions (XRPD) were collected preliminarily in laboratory and successively with synchrotron radiation, using the sample inside glass capillary. Laboratory XRPD were collected using a Mo X-ray source and a CCD area detector. The instrument used was a Oxford X'calibur model. The raw 2-D data were integrated using Crysalis software, and powder patterns were analysed using H'Pert High score Search-Match program. The synchrtorn XRPD were collected on a selection of samples on ID09A beamline (ESRF, Grenoble) using a monochromatic beam (λ=0.4139 Å) and a large flat panel area detector.

3.11 - Soil micromorphology

Undisturbed samples were sent to an external laboratory for thin section preparation. An initial drying for the total water removal is followed by the impregnation in epoxy resins (polystyrene); after a variable period of duration of some weeks, necessary for allowing the resin to harden, the sample was cut and polished, to obtain a thin section about 20-30 μm thick. The sections were then observed under a petrographic microscope (Olympus BX41), al parallel (PPL), cross-polarised (XPL) and oblique incident light (OIL), using different objectives with magnification of 2, 10, 20 and 40x. Sections were described primarily according to Stoops (2003). To a lesser extent it has been referred to the terminology of descriptive system proposed by Brewer (1976) and by Bullock et al. (1985). The interpretation of thin sections was performed according Stoops et al. (2010).

For each section was followed a descriptive diagram which involved the observation of:

- Microstructure and porosity: type of microstructure, aggregate size and shape, void type, abundance, spatial arrangement, shape and size.
- Groundmass: c/f limit, ratio and relative distribution; nature, degree of weathering, size and frequency of coarse mineral and organic constituents; nature, colour, limpidity, interference colours and b-fabric of the groundmass.
- Organic matter (not part of the groundmass): nature, degree of weathering, size, frequency and spatial arrangement.
- Soil pedofeaures: nature, size, shape, variability, abundance and spatial arrangement of the different figures soil.

Compared to the standard guide of Stoops (2003), it was agreed that a number of changes should be done for reasons of tradition, of opportunities, and to facilitate the work of description.

- Frequencies related to voids should be given with respect to the total area occupied by the voids themselves. To facilitate frequency assignment, estimated through a comparison chart, it was preferred to use the whole area of the section as a reference instead.
- In the description of the coarse fraction two elements, phytoliths and charcoal, belonging to the category of inorganic material of biological or anthropogenic origin, were described instead as organic material. Phytoliths are opal bodies (composed of amorphous silica) formed within plant cells, whose shape changes depending on the type of plant and the organ from which it comes. They are therefore useful to indicate the presence of vegetation and, if possible, its type: therefore this change in classification. Charcoal was changed because of its origin: Stoops (2003) considers them belonging exclusively from human activity, so always sign of human influence. Since it is not possible in this area to assign charcoal fragments undoubtedly to human action, it was preferred to avoid this implication.
- In the description of groundmass limpidity, the term "opaque" is used to identify amorphous materials able to completely block light passage. It was preferred in this case assign this

naming to cases in which thin section were accidentally thicker than normal because of preparation, so resulting darker to the eye.

Specific features from selected thin sections were studied with a Cambridge 360 scanning electron microscope (SEM), imaging both secondary and back-scattered electrons. Some elemental analyses were performed with an energy dispersive Xray analysis (EDS Link Isis 300) requiring a carbon-coated thin section: energy dispersive X-ray spectroscopy with an accelerating voltage of 20 kV, filament intensity 1.70 A, and probe intensity of 280 pA. Analysed elements have been standardised by using several single-element standards (Micro-Analysis Consultants Ltd); elemental concentrations measured by EDS are reported as oxide weights normalised to 100%.

Chapter 4

Geomorphology of Mt Cusna ridge

4.1 - Structural influence

Tectonic structure drives the entire geomorphology of the area in subtle but considerable ways. The area is the product of a series of folds and overthrusts which shaped the present day landscape (see attachment n. 1). The main landmark of the study area, the Mt Cusna ridge (fig. 4.1a,b), from the structural point of view, is characterised by a tight fold overturned NE. Normal and subordinately reversed faults are present and show apenninic (NW-SE) and antiapenninic (NE-SW) strikes. It has the alignment characteristics of the highest peaks of this part of the chain, but in an internal position with respect to the main Apennine divide (phenomenon probably due to recent tectonics; Papani and Sgavetti, 1975; Bartolini et al., 1982). A second significant landmark, Mt, Bagioletto, shows the same anticline structure, this time overturned N. In all the area, the overthrusts are manly directed N and NE, in particular in the northern part and in the area of Mt. Cusna, where they are sometimes associated to cuestas and minor escarpments (fig. 4.1d).

Among the major structural elements there are also several fault systems. In the SE part of the ridge, a particularly evident fault breaks the continuity of the ridge itself in direction E-W (fig. 4.1c), forming a saddle in the ridge crest. From this fault another system separates and follows the ridge crest towards SE. Another important system is composed by two parallel main faults running in NW-SE direction and located in the northern part of the map. The western one is the major fault, extending far over the borders of the map. Between these two lines a strong tectonic strain affects the area and its morphology: in fact, two consecutive valleys are formed, which have been subject to strong slope movement, possibly driven by structural factor. One of these valleys is placed just N of Mt. Cusna in the area of Le Prese and is characterised by a series of erosional gullies parallel to fault direction before bending to the E at lower elevations. The second one, N to the first and E to Mt. Bagioletto is cut inside claystones just between the two faults, where is present a lithological discontinuity with

Fig. 4.1 - a) view of the fold of Mt Cusna from SE; b) the ridge seen from Mt. Cusna; c) fault forming a vallley on the SW slope of the ridge; d) marlstones overthrusting on claystones N of Mt Cusna.

sandstones at both sides. Two other main faults lie on the N side of Mt. Bagioletto in direction N-S., cutting the entire Mt Bagioletto anticline perpendicularly in three portions. These get progressively lower in elevation going W and have been related to a Holocene uplift phase (Panizza et al., 1982),

Also, structural influence is great in the detachment of deep seated gravitational slope deformations (DSGDS), which are widespread in this area and are strongly constrained by structural features as bedding and fractures (Radbruch-Hall, 1978; Crosta, 1996; Kellogg, 2001). In particular, the ones on the N side of Mt. Bagioletto seem directly related to the phenomena above described. As for the ones on the SW side of the ridge, they are probably the side result of tectonic strain from the general compressive forces involved in the formation of the main folds and overthrusts.

4.2 - Glacial and periglacial forms

4.2.1 - Overwiew

Considering the importance of glacialism in Italy as a powerful tool in the reconstruction of landscape evolution, especially in the Alps, there is a surprisingly small number of works in literature about Apennine glaciers. Most of the attention is taken by the Central Apennines, mostly for bearing the last Apennine glacier, the Calderone glacier. In comparison, work on the Northern Apennines are very sparse and local. The last comprehensive reviews which comprises the area of study have been made by Losacco (1949, 1982). In the former one in particular, the area of Mt. Cusna is already described as subject to glacier activity in the Northeastern side of the ridge, described as “a slope with no remarkable valley cuts, but a high and almost uniform bastion, eroded in the upper side by small cirques on the foot of which extends an highland”. On this were essentially recognised and roughly sketched the main cirques and till deposits present.

In more recent times, Panizza et al. (1982) used this work to compile their geomorphological map, significantly extending the area and the number of forms with glacial influence, though limiting their observations only to the N and NE slope of the ridge. Before starting their dissertation about glacial and periglacial landforms, they explicitly comment about the difficulty of properly recognising and attributing forms to these processes due to the peculiar nature of the substrate. This happens to be a main problem not only in the correct interpretation of a limited set of forms such as those derived from glacial activity, but also a strong forcing on the evolution of the landscape in general. Sandstone lithologies can often form, in their natural mechanical and chemical weathering process, a particular facies of subangular and subrounded blocks well conserved inside a sandy-silty matrix. When claystones are also present, the result is the same facies inside a finer matrix. These can cause a great deal of confusion, since it can be readily mistaken for deposition of till in areas of weathering outcrops. More so in the case of many slope deposits, where weathering is eased: in those circumstances, the presence of deep cuts exposing the base of the deposit are the only opportunity to get a precise attribution. Also, still due to the lithology, striations and other marks of glacial transport are usually lost on the surface of the blocks because of rapid weathering. This being the case, some deposits attributed to glacial activity by past authors have been interpreted differently here. The idea underlying this decision was usually derived by an Occam razor approach to situations which could more easily be explained by the presence of processes other than glacial ones.

4.2.2 - Northeastern slope

Cirques are among the most evident glacial features present in the study area. Several different ones can be found from the Alpe di Vallestrina station up to Mt. Cusna. Their shape is usually clearly recognisable as ample niches inside the upper, non forested portion of the NE ridge, with sharp upper crest and steep slopes, though more or less eroded and modified by slope processes. Usually these slopes are interested by deposition of cryoclastic debris which forms more or less defined deposits, in some cases in crescent forms attributable to protalus ramparts. Till deposits should usually start at the end of these niches, but they are often reworked and redeposited by slope processes at lower positions, and as of now their place is taken by more or less developed talus sheets, sometimes covering the till deposit itself.

Till deposits are well extended. They cover the most part of the lower NE slope in a continuous sheet more or less 10 km^2 wide from Mt. Contessa to Alpe di Vallestrina. The lowest point reached by moraine arcs, outside the map, is around 1100 m. The upper appearance of till deposits is variable according to the degree of their erosion. A striking example is at the summit of Mongiardonda, an isolated capping of till surrounded by a successive event of erosion and deposition of talus debris. The uppermost appearance of till is N of Sasso del Morto where a relatively small deposit closes one of the cirques at around 1950 m, forming an isolated seasonal tarn fed mainly by snowmelt water.

Starting from the south-eastern portion of the map the analysis of the main forms shows different processes acting. The Alpe di Vallestrina cirque is without doubt the best conserved (fig. 4.2a). it has been carved inside the escarpment of a cuesta dipping SW, thus being relatively more resistant to weathering and allowing conservation of the previous landforms. The cirque sides are clear and well rounded as the upper crest. Debris deposition inside the cirque is relatively small, and does not prevent the identification of the higher elevation glacial deposits. In front of it a clear step is present, marking the end of the cirque.

The cirque NW to it, below Il Passone, is less conserved due to the outcropping marlstones at the centre of its crest, which were easily eroded, deforming the previous asset of the cirque. Deposition is stronger and various lobes of small slope movements were formed over time, covering part of the till deposit (fig. 4.2b). From here several streams cut the bottom of the cirque by 2-3 meters exposing part of the underlying till, and then the deposits outside the step. These cuts follow a sequence of concentric ridges that have been interpreted as lateral moraines by past authors. This is yet quite uncertain as there are signs pointing to an effect of stream erosion. These main streams recollect at a

Fig. 4.2 - a) well conserved cirque in Alpe di Vallestrina; b) slope movemets inside a cirque in the Passone area; c) avalanche mitigation works inside the Mt La Piella cirque; d) closed cirque N to Sasso del Morto seen from the till deposit.

lower altitude and cut deeply into the deposits, exposing the rocks beneath and dividing the till sheet roughly into two equal extensions. Interpretation of the deposits inside and right below this cirque are complicated by the presence of the southern slope of Mongiardonda, which was evidently stripped of its till cover part of which seems to have been redeposited inside the cirque itself.

Between Mongiardonda and Mt. La Piella a steep valley is formed by the presence of a fault lying in the W-E direction. Inside this valley there are still deposits resembling till of uncertain origin, probably the remains of the Mongiardonda till cover. The Mt. La Piella cirque has been heavily altered by human activity in the last 50 years, when ski resorts and facilities were built here (fig. 4.2c). It can be divided in two sides. The southeastern one has been conserved, like in Alpe di Vallestrina, by its derivation form a structural escarpment. Inside the circus there is a small tarn around which two arcs and a drain have been built for avalanche mitigation. The side of this cirque is also interested by deep vertical erosive cuts following the dip of the strata. The northwestern side is the most interested by ski activity. It is much larger and reaches a lower elevation than the other one, and it is filled with talus debris formed by different cliffs inside it at different positions, two of which can actually be classified as nivation hollows. It also presents three inactive small rock glaciers at different quotas, one in the position of the frontal step. The attribution of these forms is still uncertain due to the nature of the deposit itself and the absence of clear rock glacier features.

In a position N to Sasso del Morto lies the closed cirque already mentioned above (fig. 4.2d). Its eastern side is interested again as other cirques by structural cuts releasing debris inside the basin, the other side has a more gentle slope which ends without discontinuity in a till deposit which closes the cirque at north. The basin formed is almost flat, and bears the mark of a single streamline SW to NE ending in a small seasonal tarn which dries in the summer after snowmelt water disappears.

The last visible cirque is E of Mt. Cusna. It is badly preserved and contains no till deposits, but shows a complex mix of talus deposits and landslides coming form the numerous outcrops around it. A long continuous deposit of colluvial/flow origin occupies its bottom up to the end of it, which is a small hanging opening to a wide erosional slope below. The latter could have been originated as a cirque itself, but if it were there are no visible signs of this origin anymore. Another probable cirque almost hidden by successive erosion is N of Mt. Contessa. It is a large, eroded basin which closes at the end into a small river which digs its way into the rock in the valley below. What marks its nature as glacial is the presence of a large and elongated deposit of till just out of it, presently contoured on its left side by the river.

All these cirques are related to the large till deposit that extends downslope. Its form and characteristics are complex to describe. It is characterised by the presence of several moraine arcs (fig. 4.3a,b), corresponding to the various glacial advances. At least two can be recognised clearly from the map. The lowest one is composed by two wide and distinct tongues of which the southern one is partly invisible outside the map, between 1100 and 1300 m. The upper one is composed by a series of smaller arcs between 1400 and 1550 m. Another even lowest advance is reported by other authors (Panizza et al. 1984) around 850-950 m. In between these clearly visible arcs appear a series of possible smaller ridges, sometimes in position geometrically difficult to interpret. Many of these could be only apparent

Fig. 4.3 - a) moraine arc seen from the front; b) moraine arc with scattered erratics; c) erratic on till deposits; d) protalus rampart E of Mt Cusna.

for different reasons. First, the thickness of the deposits: this till layer is quite variable in thickness, but in general never goes particularly thick. As the biggest and more visible moraine arcs can easily be more than 30 m high, the rest of the deposits share a much thinner size. In places where rivers manage to cut through this layer, the global thickness can be usually scaled down to 15-10 m or less. In this case, the original morphology covered by the glaciers and their deposits could still be relevant and influence the landscape above. Another reason for the formation of these ridges is related to the history of the deposits itself. This till in many areas shows signs of lobes and ropes typical of materials reworked by frost. These are almost impossible to see at field scale due to the nature of the material and the environmental conditions, but can be inferred with 3D imaging. This can mean a lot of the ridges previously indicated as moraine arcs could be actually originated by rock glaciers in the first stages of the Holocene, before the rise of the forest. These movements have anyway conserved many erratic blocks several meters wide still visible inside the forest (fig. 4.3b,c).

These are not the only examples of periglacial processes in the area. As said above, nivation hollows are quite common in the upper portions of the ridge, helped in time by the heavy accumulation of snow in this area. Despite their presence, other snow landforms like protalus ramparts are quite few and scattered (fig. 4.3d). This is probably due to a high rate of debris homogenisation on slopes.

4.2.3 - Northern slope

On the northern slope of Mt. Bagioletto a wide expansion of glacis deposits has been found. This surface is composed by a regolarized layer of angular blocks and gravel in a silty matrix. The orientation of these clasts is mainly random with some small domains apparently sparsely oriented in the slope direction. It starts from elevations between 1400 and 1200 m to get down to 700 m, outside the map borders. These deposits were already recognized in past works (Losacco, 1949), yet attributed to moraine activity. More recently (Panizza et al. 1982) they were instead correctly attributed to periglacial action in the area during the last glacial period. In fact, it has always been considered that Mt. Cusna glaciers never passed over Mt. Bagioletto, thus creating the absence of a credible source for these deposits to be moraine related.

On the whole the area between Mt. Cusna and Mt. Bagioletto seems devoid of glacial traces. This would not mean the absence of some glacial related processes through time. Most of the processes here are heavily influenced by lithology: claystones are subject to a fast and effective erosion which rapidly erases the past traces of landscape evolution. In fact, the Le Prese area has been considered a relict glacial site by past authors. We speculate a different origin for this landform, but still there is a possibility for the hypothesis of the presence of an old glacier which related forms have been completely eroded in time. What is more evident for the whole area interested by claystones is instead the presence of strong periglacial activity, forming great quantities of debris by successive

Fig. 4.4 - a) active solifluction on Mt Cusna; b) active solifluction on Mt Cusna cirque; c) probably inactive solifluction in Le Prese area; d) cliff edges probably related to glacier activity in the Ozola valley.

thermal weathering on surfaces at least partially freed from vegetation by the cold climate. These deposits were then easily transported away by gelifluction and rill erosion enhanced by the snow cover, thus shaping the rounded hilly landscape still partially present here.

Solifluction has probably been present cyclically after the last glacial period, and is still clearly active in places which are less covered by snow during winter because of slope steepness or wind action (fig. 4.4a,b). In these areas, including the summit of Mt. Cusna itself, it is possible to see the typical pillow shapes produced by solifluction. In fact, the whole area can still be subject to small diffuse episodes of solifluction when snow is late in winter or during dry years with less snow cover (fig. 4.4c).

4.2.4 - Southwestern slope

The southwestern part of the ridge, facing the Ozola valley is almost completely lacking in glacial and periglacial forms. This is not unexpected, since in this part of the Apennines glacial activity is always associated with the northern to eastern slopes and very rarely on the other sides (Losacco, 1949; Federici, 1977; Federici and Tellini, 1983), making this a climatic feature not strictly related to other processes. The only possible traces of the influence of glaciers on this side are the cliff edges present at the southernmost part of the valley at elevations between 1800 and 1700 m (fig. 4.4d). These edges have been preserved here probably because of the relative stability of this area: no similar features can be found following the valley, where slope processes are stronger. Periglacial processes are also fundamentally lacking and limited to few scattered rock glaciers recognisable through the slope. These are quite difficult to recognise for different reasons, first of all because of their similarity and close spatial relation to some active slope dynamics which they can be confused with. Two of these rock glaciers are located W of Mt Cusna. They face roughly NW and are both related to the presence of outcrops with a strong accumulation of blocks on their talus. The western one is much lower and shows a very distinct terminal lobe. The other forms a characteristic foot at its front which partially steps over the edge of the slope in front of it. Other two stay in correspondence with the limits of two deep seated gravitational slope deformations (DSGSD). They are difficult to characterise given the similarity with some features typical of these slope landforms, and have been differentiated mainly with the different orientation of these deposit from their surroundings, and the more chaotic fabric at field scale.

4.3 - Slope dynamics

The main factor controlling slope dynamics in the area is the steepness of the slope itself. Two different situations can be recognised according to this factor: steep slopes are related to higher elevations and usually associated with outcrops of more resistant rocks (sandstone in this case) or to the effect of stream erosion; gentle slopes are instead modelled on clay substrates and can also correspond to glacial and periglacial accumulations or tectonic influence.

In the first case the main process which has developed during the Holocene is the formation of talus deposits. These are widespread at both sides of the Mt Cusna Ridge and on the slopes of Mt Bagioletto and compose the majority of the deposits in the area (fig. 4.5a). Most of these deposits have been formed in the past and then stabilised: only the highest elevations show currently active talus deposition, the rest is covered by stable vegetation. Active scree and talus cones are related to the presence of active scarps, which in this area can have different origins. Many escarpments, especially in summit position, can be structural: these are particularly evident in the SW side of the ridge, where the erosion of the anticline has uncovered structural cliffs several tens of meters high (fig. 4.5b). On the NE side the main scarps are derived instead from the partial dismantling of glacial cirques, forming sometimes equally evident cliffs. In both cases erosion is mainly derived from rock and debris fall, and talus deposits are organised in a layering of successive cones which in time have formed scree-like continuous forms. Cones still conserve their form only in isolated positions or when recently deposited. On many stabilised talus deposits, especially on the NE slope, it is possible to find debris flow channels and other signs of recent activity. It is possible that these movements are related to snow and triggered by avalanches or during snowmelt.

These same debris flow channels seem to have an important role in the area. In fact they are the prominent linear element in the SW slope of the ridge, and a relevant one on the other side (fig. 4.5c). These channels are probably reactivated periodically by landslide detachment, which deposit at the

Fig. 4.5 - a) talus formation on the NE side of the ridge; b) structural escarpment on the SW side of the ridge; c) debris flow channels on talus deposits; d) complex landslide (bottom) in Le Prese area.

foot of the slope in very distinct cones. These cones are particularly visible on the SW ridge, where these channels are also used by water as preferential way for snowmelt discharge. In this case the cones may have also a secondary alluvial nature. Cones are not visible in the NE side of the ridge, since they face a more or less continuous slope without well defined steps. In this case deposits are probably more spread and easier to blend in the landscape, and lack a real shape or boundary, so they were omitted from the map. Debris flow deposits, though being probably the most widespread type of movement, are usually not really recognisable at field scale. There are some exceptions to this rule, and in some places these deposits are visible. One in particular, placed E of Mt. Cusna, seems to have partially filled the bottom of a cirque.

Other types of movement are mainly related to rock and debris slides and to complex movements sometimes difficult to interpret; the latter in particular are various in position and dimensions. One of these movements is visible in the area of Le Prese (fig. 4.5d), which could have been the remains of a wide landslide event involving the entire valley and related to tectonic causes derived from the presence of faulting in the area in the same direction of the landslide movement, as stated before. The massive size of the event can be deduced by the form of the valley itself, largely resembling a vast landslide scar. Afterwards the deposit has been deeply cut by stream erosion and is currently subject to smaller movements on its top.

When not clearly described as active, all these landslides are considered always dormant and able to be reactivated by the same geomorphic processes that formed them (Dramis and Bisci, 1998). This is in consideration of the extremely active dynamics present in the area and in general in the Northern Apennines, due to the combination of a number of different factors. Geological (lithology, structural and geotechnical/geomechanical characteristics, faults and fractures), geomorphological (slope angle, stream erosion) and climatic (glacial and periglacial processes) features have been recognised as potential causes of slope instability (Bertolini and Pellegrini, 2001 and references therein). On the other hand, precipitation is well documented as main trigger factor for landslide occurrence (Bertolini et al., 2005 and references therein). Tectonic activity has been also proposed among the causes of landsliding in the Northern Apennines in terms of rock mechanical fatigue due to their intense tectonisation (Bertolini and Pellegrini, 2001).

The last landforms related to slope dynamics are the DSGSD forms, which are present in the area both in the SW and the N slope of the ridge. They can be recognised by a series of features, mainly related to their detachment phase: many of them are in fact not clearly visible as distinct forms and can be only traced by the presence at their sides of a boundary of valleys caused by the unloading of the form itself. At the edge of the detachment line trenches are often present, sometimes associated with piping forms, which are usually filled by water to form temporary ponds.

Their occurrence can be related to different causes: the spatial and geometric relation existing between large DSGSD and other landslides and regional tectonic features is documented for the central Italian Alps (Ambrosi and Crosta, 2006; Seno and Thuring, 2006). The same is found in the Northern Apennines in the case of oriented distributions of large landslides at regional scale, spatially related to late orogenic antiformal structures (Carlini et al., 2012; Chelli et al., 2013). For these is suggested a

Fig. 4.6 - a) wide DSGSD on the SW side of the ridge; b) same as before, particular of the counterscarp system seen from above; c) formation of ponds inside trenches and unloading valleys; d) same as before, particular of piping phenomena.

control exerted by recent tectonic features on landslides distribution (Carlini et al., 2015). Still in the Northern Apennines, a concentration of large landslides has been observed in the areas affected by glacial and periglacial climate conditions during late Quaternary (Bertolini and Pellegrini, 2001). The same could be valid again for DSGSD forms as it is in the Alps, where postglacial debuttressing can have an active role in their triggering (Ambrosi and Crosta, 2006).

On the SW slope are present several DSGSD at regular intervals, presenting the characteristics noted above. The two most obvious ones, probably related to the same movement, however are quite different. Placed at about the middle section of the ridge, this system is very large and occupies the entire slope from the crest to the foot of the valley (fig. 4.6a). Differently from the other forms, the main body of the deformation has moved more than 200 m downwards, forming a vast flatter area at the top where various deposits have acted over time. Among them an extensive rock glacier has covered the main part of it, and may be the cause of the formation of much of the hummocky aspect of the area. This system is accompanied by several double crests and counterscarps (fig. 4.6b). The detachment of this DSGSD seems to be due more to tectonic causes than postglacial debuttressing: on its left side lies in fact the fault system which cuts the ridge in its southern portion. These faults also seem to act on the DSGSD itself, causing a noticeable crack parallel to them running from half the height of the deformation down to the foot.

Apart form this larger deformation, the DSGSD present on this side of the Ozola stream seem too recent to have been triggered by postglacial debuttressing from the retreat of the former Ozola glacier. Their weak movement in fact suggest a very recent origin for these landforms, which does not seem to be compatible to a Lateglacial activation (Agliardi et al., 2009). Possible causes may instead be related to very recent tectonic activity such as earthquakes.

Another important system is the one on Mt Bagioletto, where three different deformations have been found. The western one, in the Prati di Sara location, is difficult to define, since it has formed a very steep front which has been deeply eroded and partly dismantled by slope and stream dynamics, leaving at its foot great quantities of talus deposits. The other two are probably very recent and visible essentially by the presence of trenches filled by intermittent ponds and valleys caused by unloading at their boundary (fig. 4.6c,d). These could be just different portion of a single larger deformation which involves the entirety of the N slope of Mt. Bagioletto: in this sense the base of this slope, outside the map, shows a peculiar convexity that could be interpreted as the formation of a foot. This could be related principally to tectonic causes: past authors have associated this area with a recent phase of uplift started during the Holocene (Panizza et al., 1982), and this deformation would possibly be a gravitational reaction to this movement upwards.

4.4 - Washout processes

Many of the processes currently active are related to the presence and movement of water through the various elements of the landscape which in its actions has a strong influence on landform modelling. Water behaviour is constrained essentially by the differences in substrate which can be fundamental in defining erosion features. Rocks in the area are in general diffusely fractured by the effect of tectonic strain on the lithologies during the orogenic movements: as a result, they behave differently according to their nature.

Sandstones are characterised by a semipermeable behaviour and allow passage of water underground. On the NE slope the presence of many permeable deposits (talus and till above all) further enhance this effect: the water table is probably quite low as indicated by the presence of natural springs at elevations between 1400 and 1200 m. Similar conditions are present also on the other side of the ridge, where the presence of DSGSD suggests strong fracturing inside the bedrock. In these cases, the influence of water on the surface is less intense: runoff is limited and erosion is mainly in the form of stream erosion only at lower elevations where it can cut more efficiently through the deposits (on one side of the ridge) or the bottom of the valley (on the other side). When water is helped by other factors it can have a more distinct effect: this happens for example for the structural valley caused by faulting in the NE slope of the ridge. Water erosion here has been strong and has cut deeply through the fractured rock removing great quantities of sediment, as can be noted by the evolution of the stream running out of it. This has formed in time three very visible fans, one of which was then separated by a change in catchment from the Pianvallese area towards Rescadore.

When claystones and marlstones outcrop, water behaviour changes sensibly. These two lithologies share some important characteristics which practically drive most of the erosion: in fact, though being extremely fractured as the sandstones, they still retain their characteristics of impermeability and erodibility (Panizza et al., 1982). Runoff in these areas is strongly enhanced and, when in combination with a high inclination of the slopes (fig. 4.7a), it changes the aspect of entire drainage basins, as it can be clearly seen on the map. Mass wasting is strong and tends to form a dense network of hierarchical pseudo-gullies (fig. 4.7b). These catchments have in general a regular dendritic pattern, but in presence of structural influence, such as in the area of Le Prese and E of Mt Bagioletto, this pattern becomes more parallel. Activation of this process is quite swift, as can be seen in the S part of the ridge, where sandstone erosion has been uniform, forming through time a regular slope with no stream incision. As soon as erosion uncovers the marlstones below though, gully erosion rapidly cuts through the slope removing material: the result is the formation of a dendritic catchment widening at the expense of the sandstones around.

The presence of vegetation or a stable soil cover usually prevents this process (Bryan and Yair, 1982; Howard, 2009; Torri et al., 2013). When surfaces are uncovered inside a forested area the dynamic seems to be more cyclical: the barren surface is eroded forming a typical humpback form and the sediment is deposited in the immediate surroundings. If the removal of these sediments is weak these form with time a new surface over which vegetation can settle, stabilising again the slope. These

Fig. 4.7 - a) rill erosion on the steep side of a gully; b) gully formation in the N slope of Mt Cusna; c) badland-like forms in the Prati di Sara area; d) lateral erosion on colluvial deposits S of Mt Bagioletto.

humpback forms are sometimes found in the area, usually accompanied by stunted beech individuals on their ridge. This cycle is broken in case of a widespread removal of the vegetation and soil cover, which in the Apennines is usually a consequence of human activity (Torri et al., 1999, 2013; Corti et al., 2013). In this case erosion is able to remove vast amounts of material in short amounts of time, successfully preventing the formation of a new cover. With time this process can form extreme landforms. Gullies evolve forming even steeper cuts which become progressively wider and deeper slopes where vegetation fails to stabilise. The end product is a series of badland-like forms located in the area S of Prati di Sara and in the southern part of the ridge, with the largest being several tens of meters wide and developing for an elevation of more than 100 m (fig. 4.7c).

Washout phenomena are somewhat reduced on less steep slopes, especially in correspondence of vegetation or soil cover, characterised mostly by a marked permeability. Runoff processes here are connected to different types of deposition. Where runoff is ephemeral, or where it does not fit into an established washout system, it produces colluvial deposits of mainly fine material (gravel and finer), settling in more or less continuous surfaces along the sides of the slopes or, more often, to their foot. When the streams are instead inserted directly into the water system, the materials are rapidly discharged. Particularly interesting in this sense are the areas located between Mt Bagioletto and Mt. Cusna: the presence of stable and flatter slopes in these locations allowed the deposition in time of colluvial deposits which in the past probably formed a continuous layer over the foot of the slopes. These deposits are characterised by different dynamics depending on the energy of the slope, and two different mechanics can be recognised. In the flattest areas colluvium shows the characteristics of a slow movement: a mostly uniform layer of material with no sign of stratification. In this case deposits were probably produced by relatively short range runoff and successively homogenised by internal movements related to solifluction. On relatively steeper positions stratification tends to appear in the form of stonelines and multiple layers, which testify the presence of a stronger energy and a deposition possibly helped by slope movements. These colluvial deposits have been progressively stabilised by vegetation and soil formation and do not seem to be active in present conditions.

These deposition phenomena relate to a past phase of stability which in present time has changed, probably in relation to sudden changes in human impact on land utilisation. In fact, these areas are currently subject to intense washout processes in the form of diffuse surface runoff forming a diffuse system of rills and gullies which progressively cause lateral erosion of the soil cover (fig. 4.7d), exposing the bedrock below and dismantling the old surface in separate shards which will be discussed later in this chapter.

4.5 - Soils

The study of the soils and the paleosols in the area allowed to give a general characterisation of the pedogenesis on the Mt Cusna ridge. The studied profiles have different characteristics (tab. 4.1; see appendix 1) depending on various factors, among which are most relevant the lithology, the landscape form upon which they are developed, the climatic and microclimatic conditions, the vegetation cover and landscape evolution over time. This meets the equation of Jenny (Jenny, 1941) that describes the process of soil development through the interaction of the main soil forming factors:

$$s = f(cl, o, r, p, t)$$

A first general characteristic of the soils in the area is the general immaturity of the studied non-buried profiles. Pedogenesis is generally underdeveloped, characterised by a lack of strong horizon differentiation. If a typical sequence of horizons could be made, this would generally be identifiable as O - A - B(w) - BC - C, omitting in many cases the BC horizon and in other cases also the B one. This scheme is quite widespread throughout the ridge, with the obvious exceptions of younger soils and of the paleosols, the latter showing features of stronger and longer pedogenesis, and which will be extensively discussed later on. Another notable exception are soils which instead deviate from this pattern pointing to features that seem to indicate a process of podzolisation. These soils are rarely found, and their role within the pedogenesis of the area deserves a more adequate characterisation in the following chapters.

Profile thickness assumes very variable values depending on the nature of parent material, and on the morphology. In fact, maximum thickness (usually 1 to 2 m) is found in correspondence of soils formed on deposits, in particular on till, or in the case of superimposed sequences of soil developed on claystones. In this specific case, more than half of the profile thickness consists of one or more colluvial layers covering a paleosol. On the contrary, when soil is monogenetic developed on both the parent materials (i.e. sandstones and claystones), this generally does not exceed one meter of thickness above the tree limit. Below the tree limit, the soil thickness increases and often exceeds one meter. In general it can be seen how the presence of deposition has an impact on increasing soil thickness.

The colour of the soil horizons, as well, shows a clear uniformity in the area, particularly as regards the hue values. In fact, when comparing all the described soils, the hue is very rarely different from 10 YR or 7.5 YR. Different values (i.e. 5 YR or 2.5 Y) have different meanings: the former is usually related to extreme points of value and chroma and linked to local conditions of hydromorphy; the latter is usually inherited from parent material, being more common in C horizons.

Texture takes on a variety of values because of the presence in the area of two different parent materials in term of grain size. Clayey soils alternate with loamy and sandy profiles, depending on whether the substrate contains mostly claystones or sandstones. In any case the silt fractions are often present and can play a significant role.

Soil structure is never too expressed, and only in rare cases, a well separated angular structure is described, mostly related to paleosols or to the weathering of claystones. In general, granular or subangular blocky structures are found, the latter showing small size and limited to the most developed horizons of the profile.

Variability within these data collected in the field allows us to identify subsets of soils sharing common features.

Tab. 4.1 - Station descriptions for the studied profiles (Elev.: elevation (m); Incl: inclination (°); Exp.: exposition (°)).

Profile	Elev.	Incl.	Exp.	Parent mat.	Vegetation
F13-01	1619	19	30	Till	Grassland
F13-02	1624	5	339	Till	Heathland
F13-03	1769	7	338	Claystones	Heathland
F13-04	1767	5	97	Claystones	Heathland
F13-05	1764	8	299	Claystones	Heathland
F13-06	1747	7	258	Claystones	Grassland
F13-07	1755	7	308	Claystones	Heathland
F13-08	1687	18	112	Claystones	Grassland
F13-09	1680	23	11	Claystones	Grassland
F13-10	1723	9	301	Claystones	Grassland
F13-12	1764	16	82	Claystones	Grassland
F13-13	1759	18	25	Claystones	Heathland
FG13-14	1666	5	2	Claystones	Forest
FG13-15	1543	23	289	Claystones	Forest
FG13-16	1754	19	207	Claystones	Grassland
FG13-17	1658	18	312	Claystones	Grassland
FG13-18	1539	15	66	Claystones	Forest
FG13-19	1325	26	10	Till	Forest
FG13-20	1359	30	34	Deposit	Forest
FG13-21	1391	23	38	Till	Forest
FG13-22	1446	19	37	Deposit	Forest
FG13-23	1292	7	9	Till	Forest
FG13-24	1757	18	301	Claystones	Heathland
FG13-25	1701	9	266	Claystones	Grassland
FG13-26	2007	10	8	Sandstones	Heathland
FG13-27	1636	22	61	Claystones	Forest
FG13-28	1323	7	355	Till	Forest
F14-01	1983	28	51	Sandstones	Heathland
F14-02	1936	23	45	Sandstones	Heathland
F14-03	1871	20	54	Deposit	Heathland
F14-04	1847	25	40	Deposit	Heathland
F14-05	1725	32	113	Deposit	Grassland
F14-07	1753	10	324	Claystones	Heathland
F14-08	1644	13	352	Claystones	Forest
F14-08	1644	13	352	Claystones	Forest
F14-09	1642	13	233	Claystones	Forest
F14-10	1642	18	218	Claystones	Forest

Profile	Elev.	Incl.	Exp.	Parent mat.	Vegetation
F14-11	1593	10	166	Deposit	Grassland
F14-12	1233	25	77	Sandstones	Heathland
F14-13	1741	8	4	Sandstones	Forest
FG14-14	1844	11	85	Deposit	Grassland
FG14-15	1850	21	174	Claystones	Grassland
FG14-16	2044	22	19	Sandstones	Heathland
FG14-17	2088	13	292	Sandstones	Grassland
FG14-18	1731	10	338	Claystones	Grassland
FG14-19	1732	26	26	Sandstones	Heathland
FG14-20	1503	27	128	Marlstones	Forest
FG14-21	1462	23	50	Till	Forest
FG14-22	1479	11	19	Till	Forest
FG14-23	1743	24	360	Sandstones	Heathland
FG14-24	1469	27	93	Claystones	Forest
FG14-25	1643	31	37	Deposit	Heathland
FG14-26	1484	25	46	Till	Forest
FG14-27	1312	14	323	Till	Grassland
FG14-28	1449	26	29	Till	Forest
FG14-29	2066	14	90	Sandstones	Grassland
FG14-30	2056	23	196	Sandstones	Grassland
FG14-31	2026	12	206	Sandstones	Grassland
FG14-32	1989	21	176	Sandstones	Grassland
FG14-33	1962	14	169	Sandstones	Grassland
FG14-34	1930	20	178	Marlstones	Grassland
FG14-35	1587	23	321	Sandstones	Forest
FG14-36	1754	20	284	Claystones	Grassland
FG14-37	2008	20	107	Sandstones	Grassland
FG14-38	1640	29	9	Marlstones	Heathland
FG14-39	1526	20	346	Deposit	Forest
FG14-40	1934	28	243	Deposit	Grassland
FG14-41	1850	26	205	Sandstones	Grassland
FG14-42	1618	16	35	Sandstones	Forest
FG14-43	1728	7	278	Claystones	Grassland
FG14-44	1872	11	170	Marlstones	Heathland
FG14-45	1868	10	149	Marlstones	Heathland
FG14-46	1837	8	329	Sandstones	Grassland
FG14-47	1870	31	243	Sandstones	Grassland
FG14-48	1834	19	232	Deposit	Heathland

4.5.1 - Young soils

They represent the first manifestation of pedogenesis on areas in which substrate is recently exposed. There are multiple different cases of a similar situation. The first case it's about rocky ledges or cliffs where soil does not form a continuous cover, but is instead limited to the protected positions between the rocks; in this case the soil can actually not be young at all, and its apparent immaturity id due to the impossibility to develop further. It is characterised by a strong accumulation of organic matter with a typical O - (C) - R profile. More widespread is instead the case of soil forming on surfaces recently outcropped by erosion or on new deposits of more or less coarse sediment. In such conditions the mineral component is prominent since plant colonisation is still incipient and has not formed a continuous vegetation. This goes to form A - C type profiles not very thick and underdeveloped.

An example is profile FG14/30, barely little more than surface weathering in which the typical soil features are almost undetectable. The colour is mostly inherited from parent material, while the other characteristics are very poorly expressed. These soils are confined in areas where the vegetation remains as discontinuous grassland and in environments which strongly inhibit growth. More developed vegetation quickly lead to the formation of much better expressed soils.

4.5.2 - Colluvial soils

Soils formed on colluvium deserve a separate mention. These represent a later stage compared to the young soils described above, as usually vegetation over colluvial layers is already fully stabilised and it forms a continuous cover. This same cover usually shields the colluvium itself from slope erosion (which is currently underway). Colluvial soils are usually formed by a series of A - AB - AC horizons. A horizons are usually well defined and with visible structure. Soil texture is variable and inherited from the colluvium: it is usually sandy, but can reach finer values and even get clayey. In several cases pedogenesis seems more developed in the lower part of the colluvium, and some transitional AB horizons can be identified: they possess a higher chroma and a better visible blocky structure.

These colluvial soils can reach considerable thickness and also form multiple sequences. They are generally linked to the paleosurface of which they form a defining constituent, but they are often found in isolated positions, as in the case of profile FG14/15 (fig. 4.8a). This is a remarkable soil more than 120 cm deep, divided into two very similar sequences due to the deposition of two different layers of colluvium. The one in the lowest position is characterised by a stronger development of features like

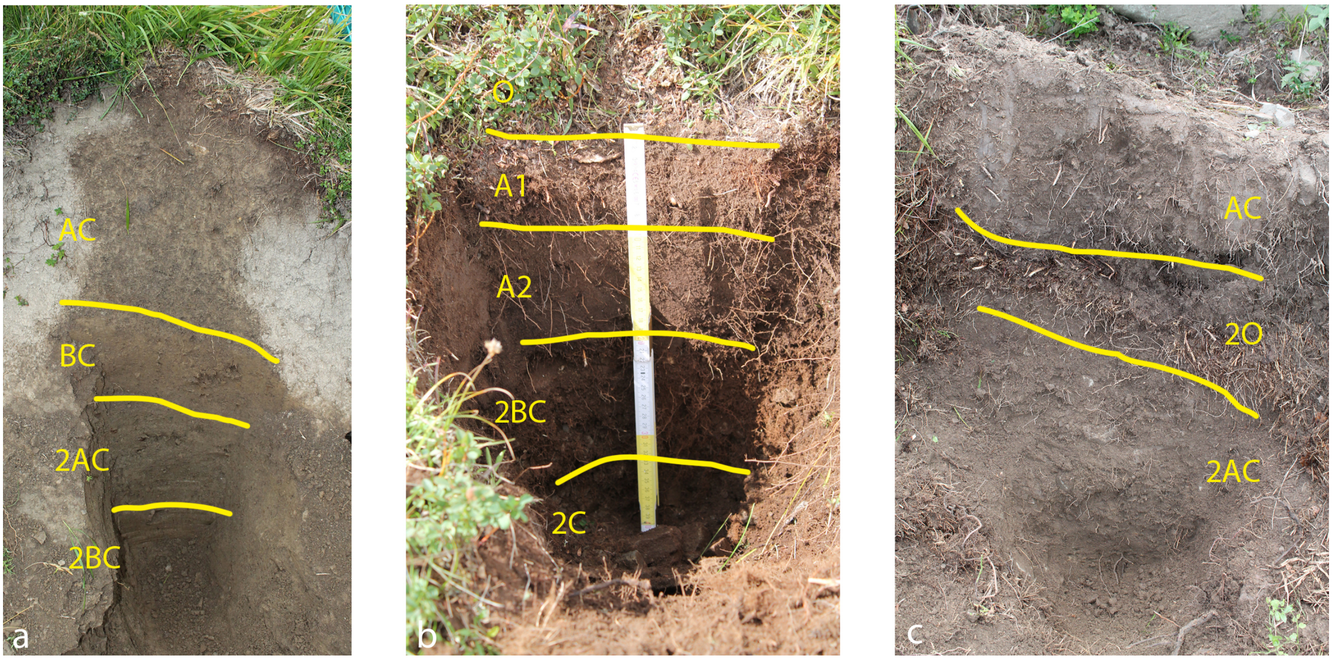

Fig. 4.8 - a) profile FG14/15; b) profile FG14/37; c) profile FG14/25.

a subangular blocky structure compared to the granular structure of the other colluvium above. This profile well represents the deposition of two distinct layer in two different moments in time

4.5.3 - Soils on talus and high altitude slopes

They are located in areas with steeper slopes characterised by general instability. In these cases, soils show features of young soils enhanced by vegetation, i.e. continuous or patchy alpine grassland. They develop in one or more sequences with a typical O - A (h) - C profile. The typical feature is the accumulation of organic matter with poor mineralization in the A horizon and presence of poorly weathered mineral components. These soils have almost always suffered phases of active slope dynamics, with episodes of removal, mixing or build-up of material at the top with the possible incipient formation of a second sequence of soil above.

A typical profile is FG14/37 (fig. 4.8b). It is a very dark soil rich in organic matter that has been accumulated several times. In fact, a lithological discontinuity marks the presence of two different layers that compose the actual soil. However, pedogenesis is very poor, as also noted by the absence of a real structure. This profile is located in an area not characterised by big or extended deposits, but still belonging to a slope with evidence of local movements, probably through solifluction in recent and, maybe, present times.

Another fairly typical profile is FG14/25 (fig. 4.8c), positioned on talus. In this case the coarse fraction is composed of large stones coming from the higher part of the slope. These have completely covered the pre-existing soil (in this case an O - AC sequence), leaving an organic O horizon completely buried. On its new surface then a new pedogenesis has begun, weathering the newly deposited parent material. Horizons are characterised by very low value and chroma: this is due to the

Fig. 4.9 - a) profile FG13/28; b) profile FG14/40; c) profile FG14/41.

Fig. 4.10 - a) profile FG14/28; b) profile F14/12; c) profile FG14/24.

accumulation of organic matter; the structure is almost absent, at macroscopic level, and the coarse mineral component is much more frequent.

4.5.4 - Soils on till and stabilised deposits

This type of soil is strongly linked to the parent material effect and to the way in which water moves within the soil itself. They are in fact soils developed on deposits in which a strong drainage is facilitated by the prevalence of coarse fraction. For this reason the pedogenesis can extend to a thickness of even 2 meters. Another typical element is the horizon articulation which is always characterised by gradual to diffuse boundaries, giving the impression of a gradual weathering of substrate, getting weaker with depth. Weathering of the coarse component of the deposit is usually very strong, and can be considered an index of the age of the deposit, in spite of the degree of pedogenesis which, despite the vertical development, does not look particularly expressed. The horizons sequence in these profiles is quite variable but generally follows the scheme: O - A - Bw - BC - C, with the A horizons often shallow and poorly. It can often be difficult to distinguish a clear separation between the soil and the unweathered parent material, and often a clear C horizon is not recognisable.

An example of this situation is profile FG14/27 in which can be noticed the extremely gradual sequence of the horizons and the soil thickness, as well as the presence of large blocks, typical of till deposits, showing a quite strong weathering.

When claystone fragments are preserved, despite the till weathering, the clay content of the soil horizons is very high and pedofeatures related to clay illuviation are present, as in profile FG13/28 (fig. 4.9a), where clay coatings do appear inside a typical till deposit.

Fig. 4.11 - a) profile F14/09; b) profile F14/10; c) profile FG13/18.

In some cases above these soils can be found multiple sequences. These have the aspect of colluvial units burying the older soil below, and are probably due to local movements of soil material triggered by slope dynamics, as visible in profile FG14/28 (fig. 4.10a).

This type of soil is not only present on till. It is also found in other areas where bedrock is sufficiently fractured and weathered to form soil drainage. An example of this is in the area interested by the largest DSGSD on the SW slope of the ridge: here are found soils perfectly compatible with those found on till on the other side of the ridge, as seen in profiles FG14/40 and FG14/41 (fig. 4.9b,c). This is due probably to the fracturing of these areas during the formation of the DSGSD itself, which formed areas with complex relief in which the substrate has undergone various stages of fracturing. It seems improper to unite in a single category soils forming in two such different conditions; still, no real characteristic was found which would allow to separate them, so they are treated as one.

4.5.5 - Soils at lower altitudes

These soils are characterised by the presence of the forest. In these areas soil formation can have a certain variability related to several factors, upon which lithology is particularly relevant. In general, soil development is more developed than at higher altitudes, and, different types of soils are found mainly related to different parent materials.

When soils are developed on sandstone, despite the duration of the pedogenesis, they are quite shallow and do not appear particularly developed; the typical horizon sequence in this case (O - A - Bw - BC) can be seen in profile F14/12 (fig. 4.10b). In this can be found clues of weak development, such as reduced thickness, along with elements that suggest strong pedogenesis instead, such as a well developed structure and a strong weathering of coarser components in the most developed horizons.

Soil appearance changes radically when parent material is claystones: in this case pedogenesis appears much more developed: thickness increases and the horizon sequence also changes (A - Bt - BC). Pedofeatures related to clay illuviation appear and colour changes, with a generally higher chroma. This is evident in profile FG14/24 (fig. 4.10c), which is also interesting for another reason: in this profile the passage from soil to parent material is extremely gradual and difficult to recognise, since the weathered clays over which soil forms are so similar in characteristics to the soil itself they are almost indistinguishable.

A striking example of the influence of these factors on soil formation is given by the profiles F14/09 and F14/10 (fig 4.11a,b). Both are located in the same geographic position a few meters away from each other. The only difference that precisely separates them is the parent material: claystones for the first, sandstone for the second. Their aspect corresponds to the before stated characteristics for each type of parent material.

Finally, in flat areas soils are better developed and hydromorphic features appear, as in the case of profile FG13/18 (fig. 4.11c): here can be found ellipsoidal mottles greyish in colour surrounded by a red rim, corresponding precisely to older porosity created by pre-existing roots, and can be related to the effect of periodical water passage inside them (i.e. pseudogley).

4.5.6 - High altitude soils on stable slopes

The most stable areas above the tree limit are rare, but have fundamental importance in the definition of the soils of the area. They probably represent the closest to soil potential for the area. In fact, soils formed here share some important common features. They are not very deep soils, never more than 1 m thick, usually not formed on deposits but lying directly on the bedrock. The standard horizon sequence is usually O - A - Bw - BC - C, regardless of substrate, as profiles FG14/32 and

Fig. 4.12 - a) profile FG14/32; b) profile FG14/33; c) profile FG14/19.

FG14/33 (the first on sandstones, the other on marlstones; fig. 4.12a,b) show. Variations may be due to organic matter content and then to the thickness and characteristics of the A horizon. This can be seen in profile FG14/19 (fig. 4.12c), where two distinct O horizons and a thicker A horizon with a blackish colour (low chroma and value) are present. Such difference may be caused by slope orientation: in fact this last profile is clearly oriented N, a factor which reduces the overall amount of energy available to the soil thus slowing mineralization of the organic matter; the former two are instead oriented SW, and organic matter here does not accumulate to the same amount.

These stable areas are also critical to the presence of the most important element on the Mt Cusna ridge. Flat and stable areas are usually interested by the accumulation of material from slope movements, which accumulate on these surfaces slowly burying them. This has also happened in some of these areas, and the result at present forms the so-called Mt Cusna paleosurface.

4.5.7 - The Mt Cusna paleosurface

This subset implies a series of soils that are found at different heights and positions along the Mt Cusna ridge. These soils share a number of features which will be discussed in detail, as this is a key element in the reconstruction of the history of soils and landscape through the climate changes of the area during the Holocene.

The paleosurface has been recognised and described partially in one of its main portions by recent studies (Panizza et al., 1982; Compostella et al., 2012; Compostella et al., 2014). This is not a continuous surface, but of a series of separated shards, currently subject to lateral erosion, which, however, share a common genesis. At a pedological level, generally can be defined as a sequence of one or more soil units formed at different times, and is usually composed by older units variously

Fig. 4.13 - a) profile F13/04; b) profile F13/05; c) profile FG14/29.

truncated and buried by colluvial deposits which form the more superficial units. This sequence can be recognised in the field by a well determined series of characters. The buried portion (i.e. paleosols) has in fact the characteristics of a well developed soil: the typical sequence is 2Bw/2Bt - 2BC - (2C) overlying the parent material, usually composed of finer lithologies as claystones and marls but also sandstone at higher altitudes.

The colluvial unit has a variable thickness ranging from 30 up to 110 cm. It is composed by one or more A horizons, underlain sometimes by AB horizons. In some colluvial unit, a weakly developed B horizon is also observed. On steeper areas can be recognised more than one colluvial layer, effectively creating more colluvial units. Field descriptions of the horizons of the upper unit show recurring characteristics: they contain few weakly weathered rock fragments above 2 mm, and show very low chroma (2 to 3 wet); texture is silty/loamy, usually more clayey with depth.

The deeper unit is characterised by a sequence of 2B horizons with increasing degree of development. At its top can be found one or more moderately developed 2Bw horizons, silty/loamy or more clayey, with rare coarse fragments; structure is always blocky, but variable in size and development; colour possesses an higher chroma than above. The lowest part of the unit can be composed by well developed 2Bt horizons with clay illuviation features; they show a well defined aspect in the field: texture is always at least partly clayey and structure always blocky, coarse material is generally rare, and colour has the highest chroma in the profile. The base of the profile is usually marked by a clear contact with the substrate, often fragmented in centimetric blocks; in some profiles the passage between soil and bedrock was gradual, with a dark, clayey saprolite-like forming 2BC intergrades below the 2B horizons.

An organic buried 2Ab horizon is not always present at the top of the deeper unit (e.g. F13/03, F13/04, F13/05; fig. 4.13a,b): its colour has the lowest value, looking very dark-blackish, and presented a very loose fine structure with almost no coarse material; it also contained very few macroscopic charcoals. Because of its characteristics, which will be treated in the following chapter, this horizon is considered as a soil unit by its own, with the horizons below belonging to a third soil unit.

The lowest elevation at which the paleosurface is found is below the treeline, around 1650 m (F14/09 and F14/10). Above 1850 m the features of the buried unit become less and less visible, but can be recognised up to the top of Mount Cusna. Laterally, the paleosurface extends on the N slope of Mt Cusna, with isolated shards towards E and W of it. Other isolated points have been found southward, from both sides of the ridge at Mongiardonda and S of Il Passone. Soils belonging to it were also found of the ridge crest. Profile FG14/29 (fig. 4.13c) has particular characteristics that help in reconstructing the development of these soils. Here, in fact, are present 4 different soil units which clearly resemble to repetitions of the same one: an organic horizon buried with characteristics similar to the 2Ab horizon found in other areas (and to which the same name was given), with a weakly weathered Bw horizon below.

Chapter 5

Laboratory analysis on soils

Laboratory analyses allowed to get a very detailed knowledge of soil features from the sampled profiles. Among soil profiles described in the field 23 profiles were selected for laboratory analyses. Among these six profiles, belonging to the already described paleosurface, were subject to a complete analytical set: these analyses are primarily focused on the soil chemical components and particle size, together with iron extractions and the identification of the clay minerals. These profiles were chosen from different geomorphic positions and under different conditions: profiles F13/04, F13/05 and F13/06 are located relatively close together in the northern part of the paleosurface; further S is located profiles F13/12. F13/10 is instead located E of Mt Cusna while profile F13/08 is in the southernmost portion of the ridge. A further series of 17 soil profiles not belonging to paleosurface has been subject to a narrower analytical set, in order to give a brief characterization of the entire area: in detail, the determination of pH and organic matter, particle size and iron extractions were performed.

5.1 - Particle size analysis

As for the grain size, the soils in the area seem to share certain features (fig. 5.1a,b,c,d). Examining the relative percentages of fine earth in the analyzed soil profiles it can be seen that the sand often plays an extremely limited role compared to the silt and clay. In fact, sand content becomes relevant only where soils develop on sandstone parent material (e.g.: FG13/26, FG13/28, FG14/32): in such a case its percentage can exceed 40% in the deepest horizons of the profiles. Moreover, sand sometimes reaches the threshold of 30-40% in the colluvial horizons of the paleosurface, as for example in profiles F13/03, F13/06 and F13/08, when clay plays a minor role, confined to no more than 20% of the total fine earth, usually less.

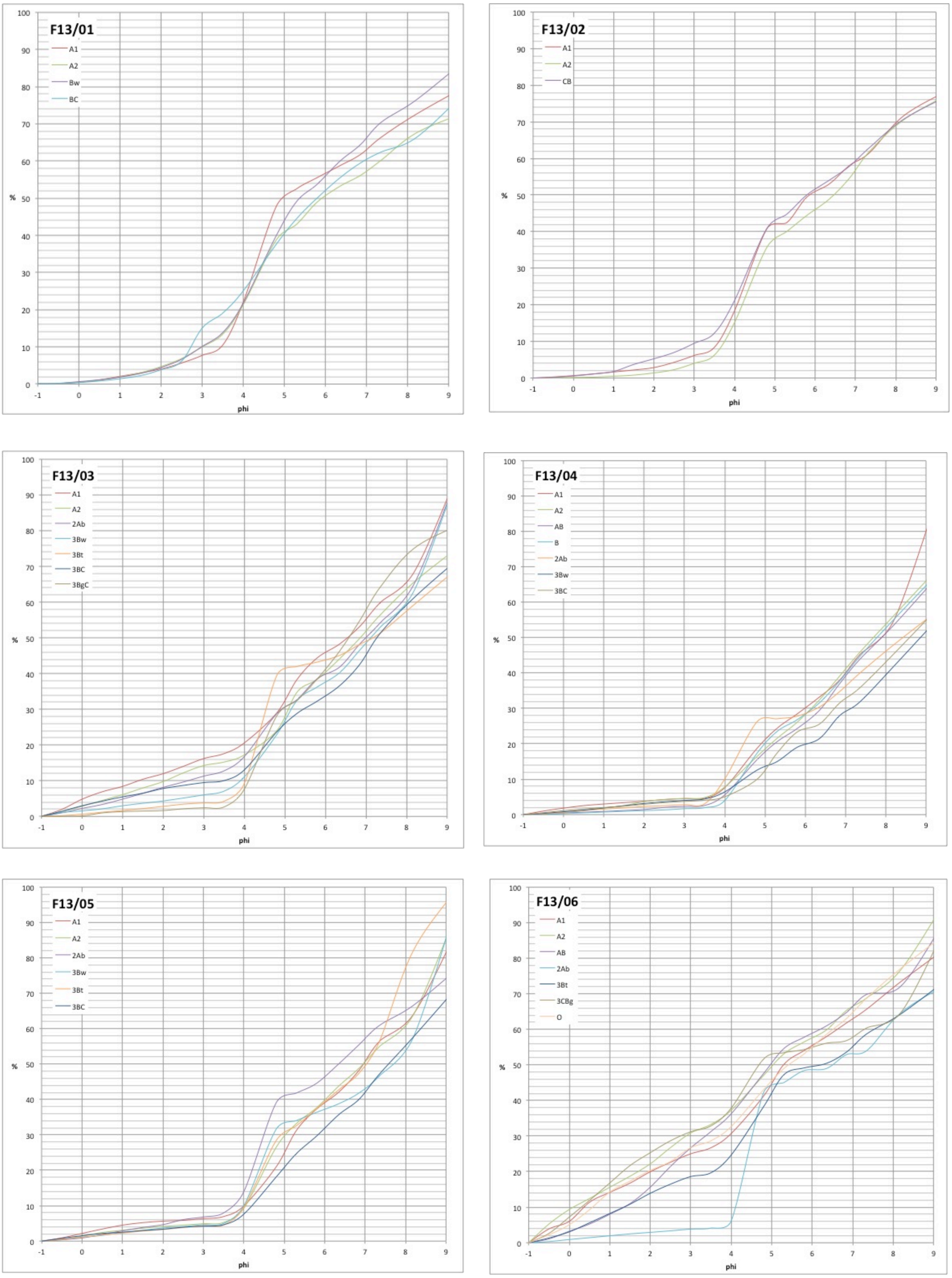

Fig. 5.1a - Cumulative curves of grain size distribution in the studied profiles

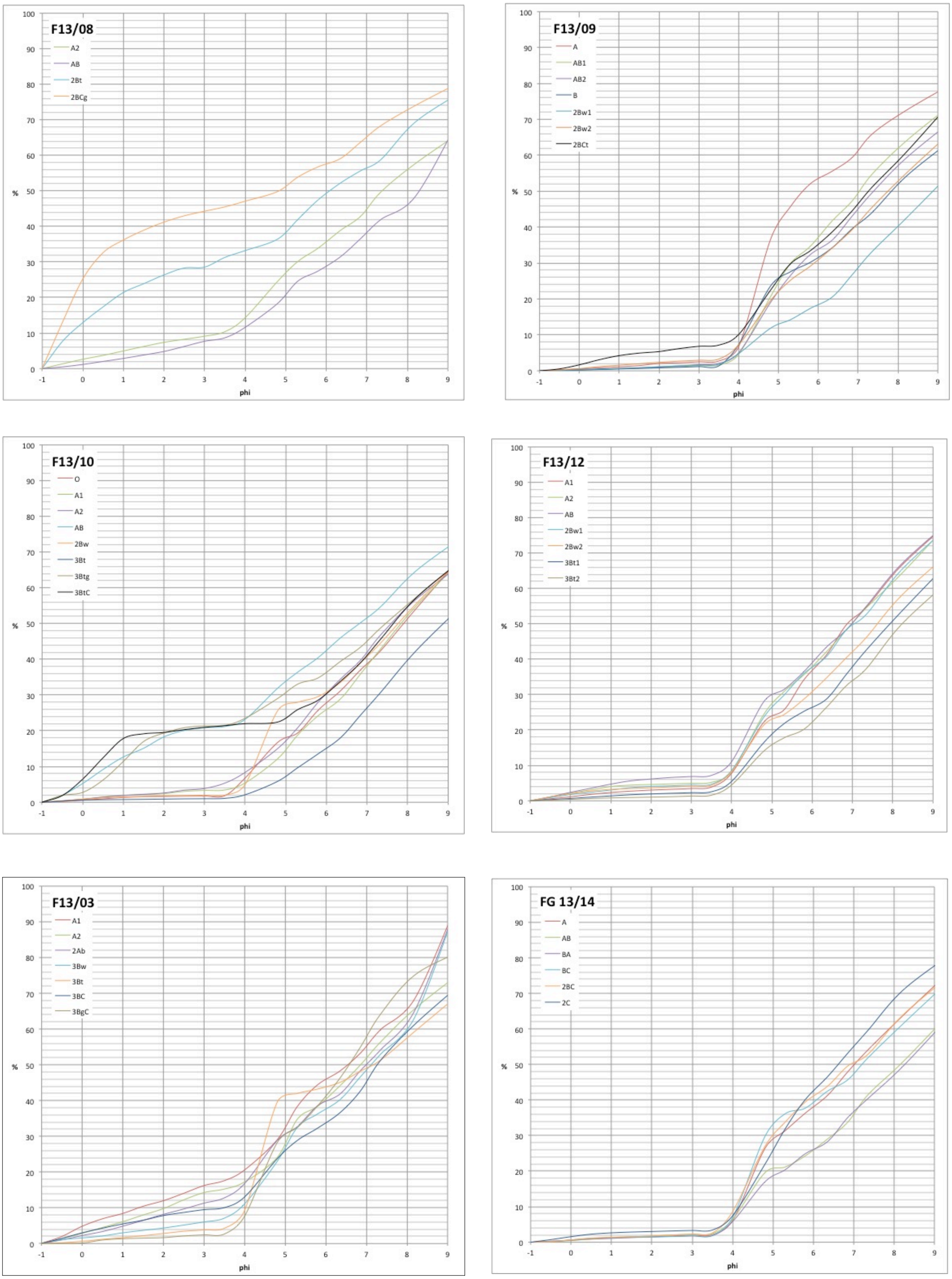

Fig. 5.1b - Cumulative curves of grain size distribution in the studied profiles - continued

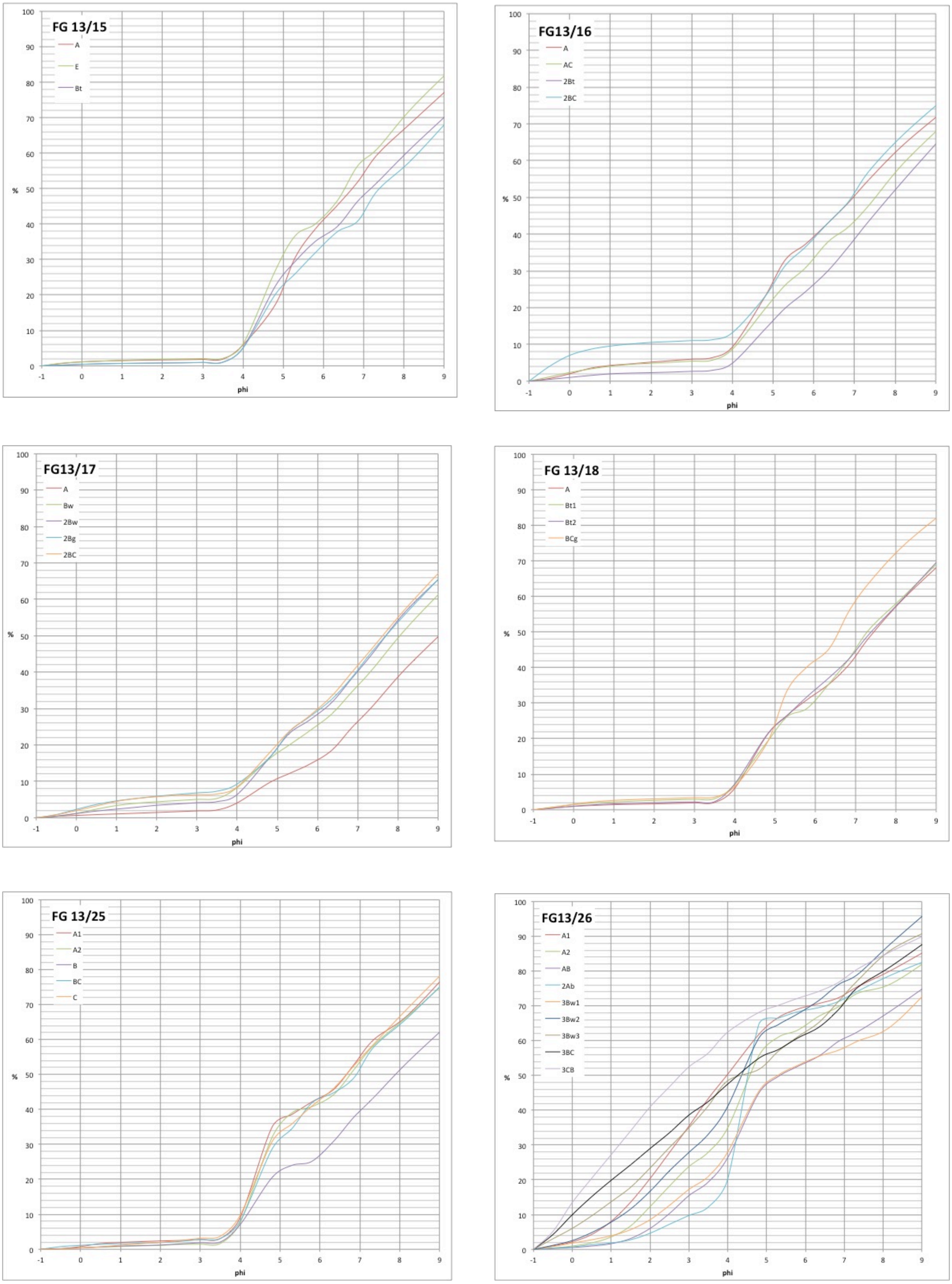

Fig. 5.1c - Cumulative curves of grain size distribution in the studied profiles - continued

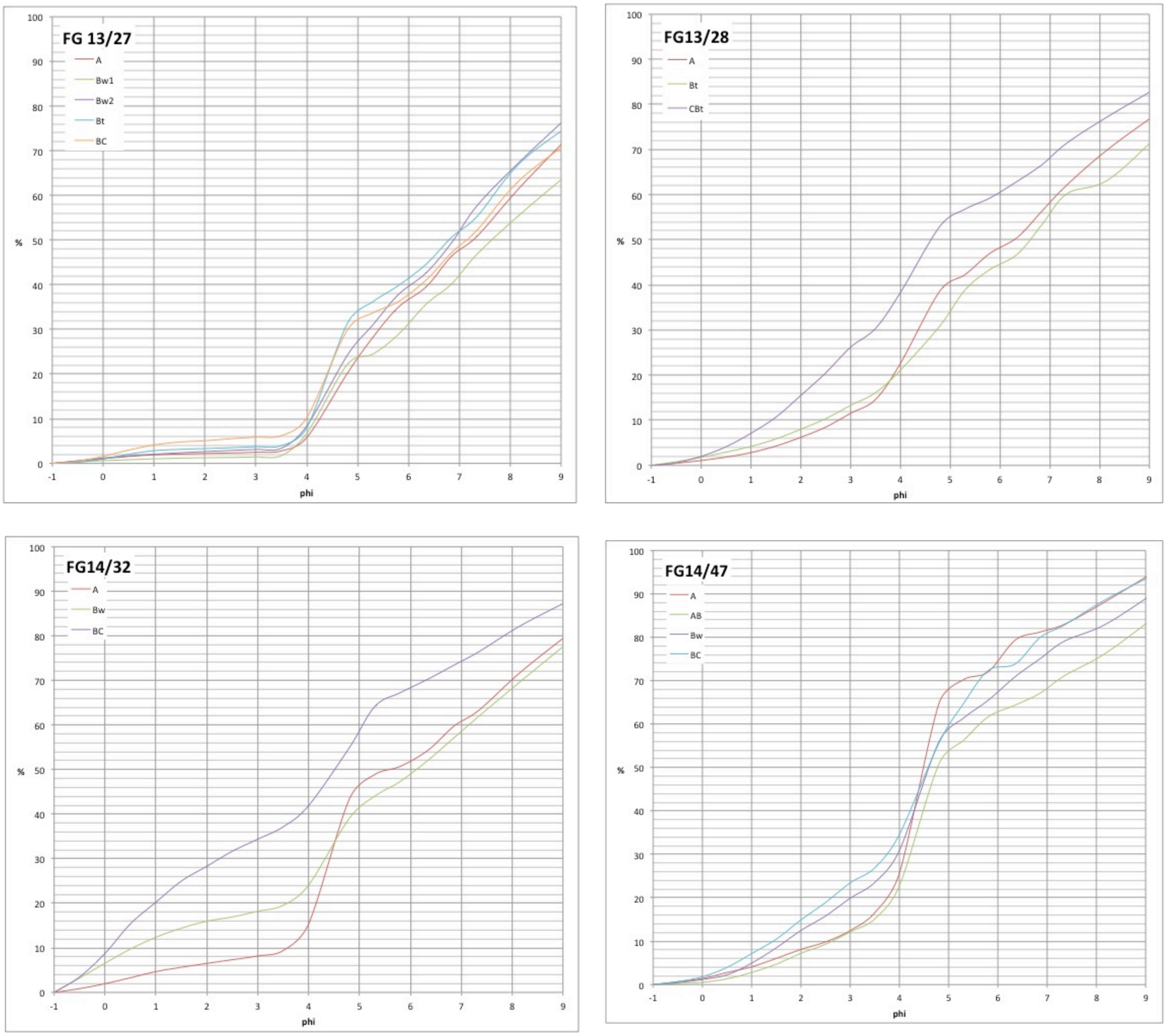

Fig. 5.1d - Cumulative curves of grain size distribution in the studied profiles - continued

On the contrary, in the areas with clayey parent material sand amount rarely exceeds 10%: in particular, cumulative curves show a constant increase in frequency towards the finest fractions. In these soils the most represented size class is usually silt, which can reach a total frequency of more than 50%, with some extreme cases (2Ab horizons in particular) up to 80%, while, in many soils clay consists of no more than 30%. This last value is not a constant boundary: there are cases, usually related to the buried units of the paleosurface, where clay exceeds the 30% and can reach amounts of more than 40% with a peak of 50% in one 2Bw horizon in profile F13/09. Variations inside the profiles aren’t particularly well expressed, but sometimes the higher clay content can be indicative of the most weathered horizons respect to the least weathered.

With regards to the paleosurface profiles, particle size analysis confirms the textural diversity between the colluvial surface units and the units buried below. Colluvial units generally show a greater relevance of the sand fraction, paleosol units are much richer in clay and silt. This difference is quite

Tab. 5.1a - Results from soil chemical analyses (pH, organic carbon, iron forms)

Profile	Horizon	C org (g/kg)	pH (H2O)	pH (KCl)	Fed (g/kg)	Feo (g/kg)	Fed-Feo (g/kg)	Fetot (g/kg)	Fed/Fetot (%)	Feo/Fed (%)	(Fed-Feo)/ Fetot (%)
F13/03	A1	24,28	5,54	4,35	14,67	3,68	10,98	49,6	29,57	25,11	22,15
	A2	12,25	5,03	3,85	17,76	4,43	13,34	46,82	37,94	24,92	28,49
	2Ab	17,1	5,32	3,64	18,61	4,63	13,98	48,22	38,6	24,87	29
	3Bw	18,55	5,49	3,55	20,9	7	13,9	44,9	46,55	33,48	30,97
	3Bt	24,91	4,63	3,69	30,82	12,48	18,34	58,42	52,76	40,5	31,39
	3BC	12,24	5,91	3,75	27,44	10,49	16,95	63,03	43,53	38,24	26,89
F13/04	A1	34,63	5,15	4,02	15,32	5,76	9,56	48,80	31,40	37,58	19,60
	A2	9,84	5,12	3,72	15,38	6,06	9,32	47,78	32,18	39,38	19,51
	AB	9,99	5,03	3,66	18,07	6,93	11,14	40,75	44,34	38,34	27,34
	B	12,24	4,78	3,63	15,91	8,56	7,35	49,46	32,17	53,79	14,87
	2Ab	19,71	4,20	3,40	34,77	18,26	16,51	54,25	64,09	52,52	30,43
	3Bt	17,99	4,53	3,52	14,85	11,06	3,79	52,67	28,20	74,46	7,20
	3BC	6,61	4,53	3,43	17,91	7,78	10,13	53,52	33,47	43,45	18,93
F13/05	A1	31,08	5,45	4,15	17,28	8,72	8,55	48,25	35,80	50,48	17,73
	A2	27,02	5,37	3,97	15,81	6,83	8,99	46,65	33,90	43,17	19,26
	2Ab	87,24	4,91	3,46	15,33	7,52	7,81	30,30	50,59	49,03	25,78
	3Bw	34,41	4,85	3,67	30,24	15,84	14,40	50,63	59,72	52,38	28,44
	3Bt	16,12	4,70	3,74	19,67	14,57	5,10	51,06	38,53	74,06	10,00
	3BC	1,97	4,60	3,65	18,50	5,86	12,64	57,73	32,05	31,69	21,90
F13/06	O	46,71	5,01	4,05	11,53	5,39	6,14	48,72	23,67	46,78	12,60
	A1	21,69	4,76	3,57	16,63	7,31	9,32	50,08	33,20	43,97	18,60
	A2	12,72	4,82	3,42	15,38	8,48	6,90	51,88	29,65	55,11	13,31
	AB	21,42	4,69	3,55	20,73	7,59	13,14	42,06	49,28	36,60	31,24
	2Ab	59,02	4,34	3,34	22,98	11,45	11,52	44,76	51,33	49,85	25,74
	3Bt	24,71	4,46	3,60	24,52	17,09	7,42	48,70	50,34	69,72	15,24
	3BCg	4,52	4,49	3,32	13,44	5,71	7,74	43,62	30,82	42,45	17,73
F13/08	A1	125,90	5,64	4,13	12,56	8,03	4,53	43,88	28,63	63,93	10,33
	A2	40,62	5,28	3,99	12,01	8,33	3,68	44,49	26,99	69,35	8,27
	AB	31,67	5,27	3,75	16,17	9,13	7,05	40,98	39,46	56,43	17,20
	2Bt	8,72	5,13	3,85	15,81	12,41	3,39	54,54	28,99	78,53	6,22
	2BCg	4,92	5,15	4,02	12,19	9,48	2,71	52,20	23,35	77,76	5,19
F13/10	O	7,85	5,53	4,39	12,89	4,44	8,45	44,42	29,01	34,44	19,02
	A1	11,59	5,46	4,07	12,03	4,56	7,47	47,75	25,20	37,93	15,64
	A2	8,25	5,51	4,09	16,08	4,96	11,12	47,12	34,12	30,85	23,59
	AB	10,09	5,22	3,85	14,24	6,21	8,03	44,32	32,13	43,60	18,12
	2Bw	8,42	5,18	3,80	14,21	5,40	8,81	52,95	26,83	37,98	16,64
	3Bt	13,36	5,10	3,74	14,33	9,41	4,92	46,36	30,91	65,65	10,62
	3Btg	5,32	4,76	3,77	14,80	8,00	6,80	47,58	31,10	54,06	14,29
	3BtC	4,24	4,76	3,84	12,03	4,63	7,40	43,07	27,92	38,51	17,17
F13/12	A1	54,04	6,43	5,52	12,09	5,23	6,85	43,57	27,74	43,30	15,73
	A2	24,78	6,10	5,02	10,72	5,57	5,15	43,08	24,89	51,97	11,95
	AB	15,47	5,57	4,32	11,42	5,21	6,21	46,75	24,43	45,62	13,29
	2Bw1	10,22	5,67	4,08	11,44	5,84	5,60	47,75	23,96	51,05	11,73
	2Bw2	20,53	5,54	3,80	13,56	5,45	8,11	53,74	25,23	40,19	15,09
	3Bt1	21,12	5,22	3,89	17,49	10,00	7,49	45,08	38,81	57,17	16,62
	3Bt2	17,73	5,18	3,86	27,29	15,00	12,29	45,08	60,53	54,97	27,25
F13/13	A	15,84	5,23	4,03	16,65	3,47	13,18	45,46	36,62	20,84	28,99
	BA	9,50	4,86	3,81	18,26	4,68	13,58	43,26	42,21	25,62	31,40
	2Bw1	6,11	4,81	3,8	17,17	5,29	11,87	49,88	34,41	30,84	23,80
	2Bw2	3,52	4,8	3,75	17,12	4,59	12,53	42,18	40,59	26,84	29,70
	3Bw	13,68	4,55	3,73	20,66	8,81	11,85	45,08	45,83	42,63	26,29
	3Bt	15,20	4,26	3,71	30,30	15,01	15,29	49,77	60,88	49,54	30,72
FG13/15	A	24,12	4,3	3,53	15,77	2,78	12,99			17,60	
	E	9,50	4,73	3,81	14,72	1,21	13,51			8,24	
	Bt	3,04	5,04	4,04	17,23	2,64	14,59			15,31	
	BtCg	6,08	5,22	3,94	18,20	4,24	13,96			23,29	
FG13/26	O	78,93	4,56	3,48							
	A1	65,91	4,63	3,54	10,94	4,93	6,01			45,09	
	A2	52,31	4,58	3,34	11,60	6,42	5,18			55,37	
	2Ab	76,42	4,51	3,5	39,85	26,50	13,35			66,50	
	3Bw1	45,85	4,47	3,61	38,17	21,75	16,42			56,99	
	3Bw2	14,65	5,58	3,71	18,32	11,13	7,19			60,77	
	3Bw3	11,50	5,59	3,75	13,19	5,31	7,88			40,27	
	3BC	6,06	6,02	3,9	9,92	4,22	5,70			42,53	
FG13/27	A	37,18	4,15	3,59	23,60	12,03	11,56			51,00	
	Bw1	23,76	4,39	3,64	28,35	8,72	19,63			30,77	
	Bw2	13,58	4,65	3,63	27,87	14,10	13,77			50,58	
	Bt	7,21	4,67	3,73	25,28	10,55	14,73			41,72	
	BC	6,79	4,53	3,76	20,64	8,10	12,55			39,22	

Tab. 5.1b - Results from soil chemical analyses (pH, organic carbon, iron forms) - continued

Profile	Horizon	C org (g/kg)	pH (H2O)	pH (KCl)	Fed (g/kg)	Feo (g/kg)	Fed-Feo (g/kg)	Fetot (g/kg)	Fed/Fetot (%)	Feo/Fed (%)	(Fed-Feo)/ Fetot (%)
FG13/28	A	19,01	4,44	3,65	11,70	3,42	8,28			29,25	
	Bt	13,68	4,95	3,89	15,12	3,48	11,64			23,03	
	CBt	3,80	5,31	4,1	10,13	2,85	7,28			28,15	
F14/02	Bh	57,89	4,58	3,09	13,25	5,37	7,88	20,79	63,73	40,55	37,89
	Bs	29,43	5,16	3,74	23,55	13,09	10,46	29,43	80,01	55,60	35,53
	BC	9,58	6,07	4,01	7,48	2,48	5,00	25,45	29,41	33,19	19,65
F14/07	A	130,47	4,38	3,45	10,56	2,30	8,26	41,14	25,66	21,74	20,08
	2Ab	91,38	3,82	3,27	11,97	6,78	5,19	44,90	26,66	56,61	11,57
	3Bw	9,69	5,12	3,65	20,78	5,74	15,04	47,65	43,60	27,63	31,55
F14/13	O	340,42	4,38	3,11	4,77	2,82	1,94			59,25	
	AE	102,22	4,18	3,32	8,68	5,09	3,59			58,60	
	Bh	119,52	4,33	3,47	17,46	14,07	3,39			80,59	
	Bs1	53,62	4,62	3,71	30,37	23,53	6,84			77,48	
	Bs2	23,35	4,87	3,91	18,46	14,43	4,03			78,17	
	BC	7,45	5,3	3,97	8,39	2,89	5,50			34,44	
FG14/21	A	26,56	4,65	3,51	14,69	4,70	9,99			32,03	
	Bw	12,42	4,97	3,76	15,80	5,16	10,64			32,64	
	BC	3,80	5,4	4,11	8,58	2,52	6,06			29,41	
FG14/19	O2	98,29	4,42	3,55	18,62	7,52	11,10	23,17	80,37	40,38	47,92
	A	93,23	4,29	3,25	6,72	3,00	3,72	13,38	50,23	44,67	27,79
	Bw	41,95	4,3	3,4	19,24	11,28	7,95	26,00	74,00	58,66	30,59
	BC	9,17	4,64	3,62	23,86	13,20	10,66	28,79	82,88	55,31	37,04
FG14/29	A	22,98	5,08	3,73	6,18	3,96	2,22	21,65	28,53	64,14	10,23
	2Ab	32,85	4,69	3,57	8,79	3,50	5,29	21,17	41,55	39,80	25,01
	2Bw	34,33	4,52	3,53	8,41	3,30	5,11	21,26	39,55	39,24	24,03
	3Ab	37,29	4,41	3,58	8,64	1,52	7,12	20,56	42,04	17,58	34,65
	3Bw	33,48	4,54	3,64	8,32	3,60	4,72	20,53	40,54	43,22	23,02
	4Ab	45,19	4,76	3,72	8,23	3,54	4,69	19,07	43,14	43,05	24,57
	4Bw	37,38	4,62	3,78	9,13	2,94	6,19	19,22	47,52	32,19	32,23
	5Ab	40,67	4,58	3,85	10,98	5,26	5,72	18,27	60,07	47,89	31,30
	5Bw1	33,25	4,53	3,78	11,28	5,40	5,87	21,05	53,56	47,91	27,90
	5Bw2	18,81	4,54	3,76	11,21	4,32	6,89	24,04	46,63	38,57	28,65
FG14/32	A	45,48	4,59	3,6	11,82	4,93	6,89	37,00	31,95	41,68	18,63
	Bw	22,04	4,6	3,86	15,11	5,33	9,78	40,72	37,11	35,29	24,02
	BC	8,64	4,75	3,93	12,53	2,47	10,06	42,43	29,53	19,74	23,70
FG14/43	A	25,84	4,98	3,79	14,73	6,52	8,21	43,26	34,05	44,26	18,98
	AB	23,45	4,73	3,72	16,28	6,65	9,63	41,85	38,91	40,86	23,01
	2Ab	55,05	4,57	3,61	15,68	5,25	10,44	45,44	34,51	33,45	22,97
	3Bw	15,96	4,41	3,72	16,78	5,47	11,32	48,03	34,94	32,56	23,56
	3BC	16,37	4,83	4	13,47	6,65	6,82	43,61	30,89	49,38	15,64
FG14/45	A	19,38	5,04	3,71	12,20	3,52	8,68	36,68	33,27	28,83	23,68
	2Ab	63,58	4,93	3,59	14,72	6,56	8,15	40,46	36,37	44,60	20,15
	3Bw	55,05	4,8	3,71	15,46	7,07	8,40	42,55	36,35	45,69	19,74
	3BC	39,56	4,66	3,99	15,81	8,62	7,20	39,08	40,47	54,48	18,42
FG14/46	A	88,66	4	3,21	7,26	3,22	4,05	16,76	43,34	44,27	24,15
	Bh	91,23	4,33	3,35	12,53	5,08	7,45	45,56	27,49	40,54	16,35
	Bs	49,79	4,58	3,63	27,50	16,20	11,30	51,12	53,79	58,91	22,10
	CB	6,98	4,65	3,85	16,08	7,60	8,47	44,53	36,11	47,30	19,03
FG14/47	A	61,47	4,77	3,82	13,45	9,98	3,48	31,42	42,82	74,16	11,07
	AB	56,47	4,84	3,75	16,99	6,42	10,58	33,37	50,92	37,77	31,69
	Bw	30,15	5,2	4,02	17,24	6,44	10,80	35,57	48,46	37,36	30,36
	BC	19,46	5,19	4,03	14,86	5,81	9,05	36,92	40,25	39,09	24,52

evident, as the transition between different units detected in the field is often associated with a strong variation in the grain size values. Particularly evident in these soil profiles is the behaviour of the 2Ab horizon, which usually shows an abrupt increase in the frequency of silt completely absent in the colluvial horizons overlying it. This indicates a strong presence of coarse silt which can sometimes be shared by 3Bw or 3Bt horizons underlying it. This behaviour is always visible whenever a 2Ab horizon is present with the exception of profile F13/03, where this horizon shows coarser values similar to the colluvium overlying it. There are other profiles though in which a clear passage to different soil units is not as as well detected from grain size distribution as in the field. This happens

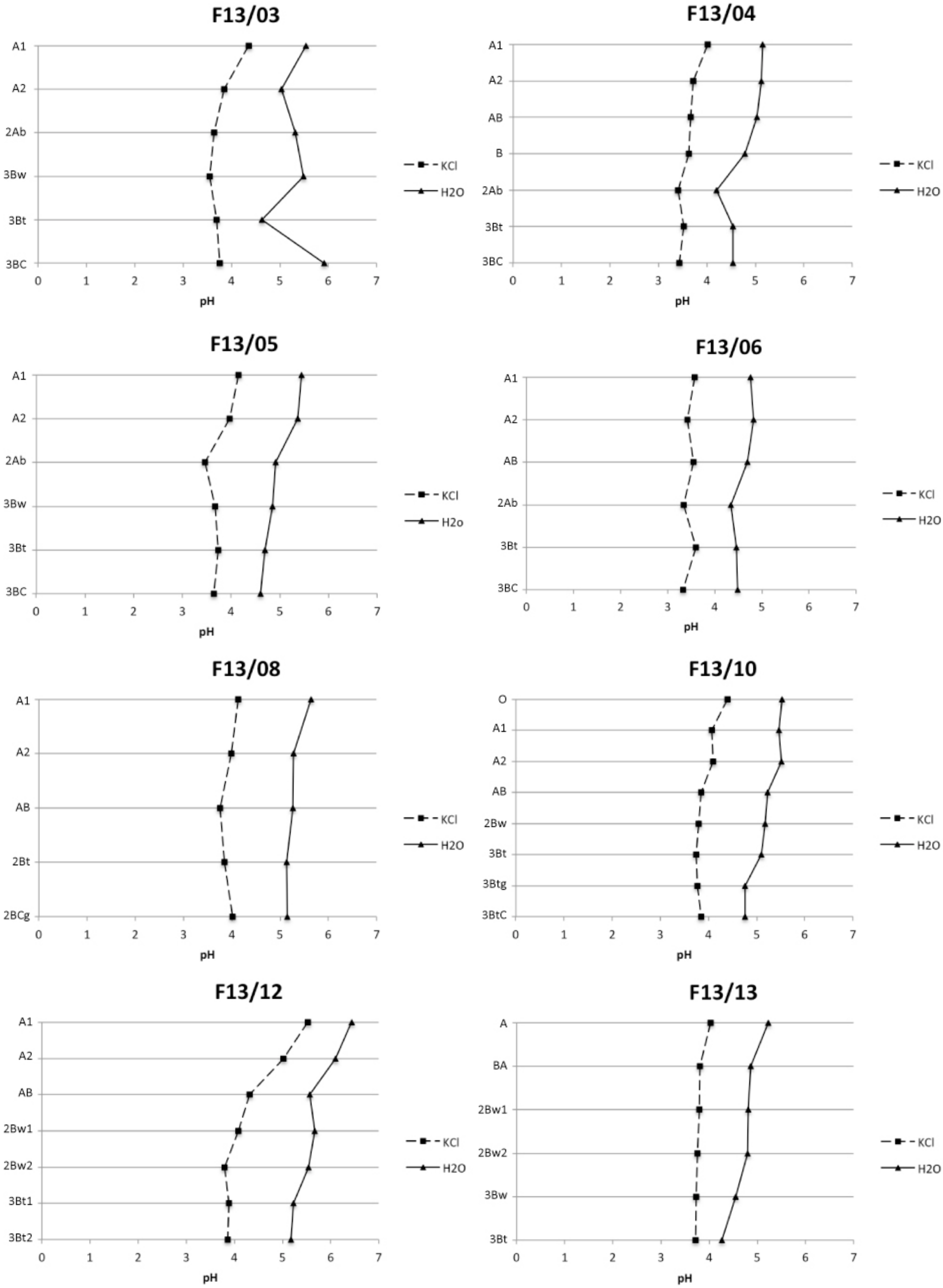

Fig. 5.2a - pH values in H_2O and KCl for the studied profiles

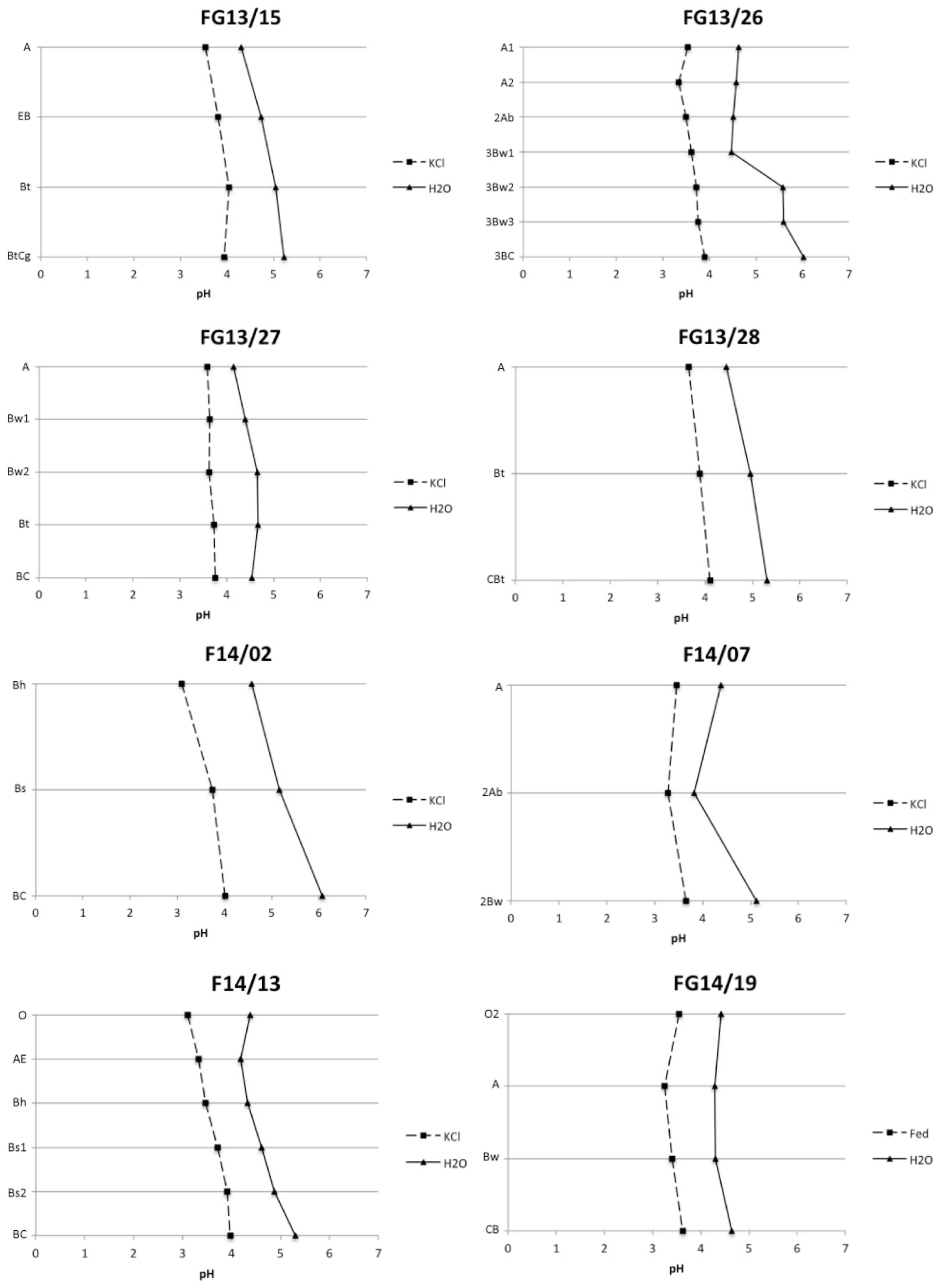

Fig. 5.2b - pH values in H_2O and KCl for the studied profiles - continued

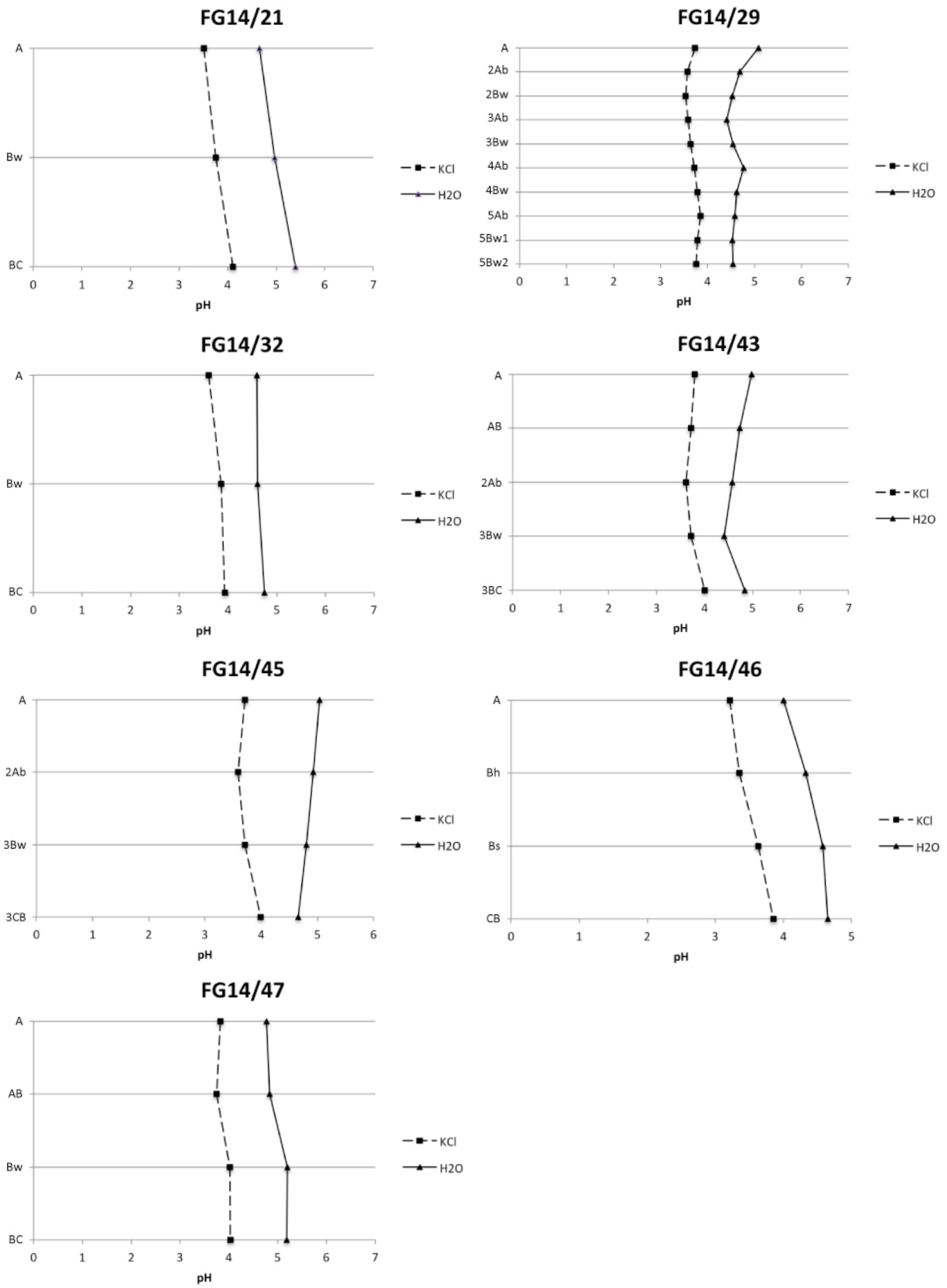

Fig. 5.2c - pH values in H_2O and KCl for the studied profiles - continued

for example in profile F13/13, where the uppermost horizon of the lower unit attributed in the field shares the same grain size distribution of the upper unit and does not correspond to the start of the increase in clay content, which happens one horizon below.

Soil profiles not pertaining to the paleosurface show less recurring grain size distributions. However, it can be identified a trend of gradual clay increase with depth to the most developed horizons, while surface horizons, as well as the deepest C horizons have a tendency to be richer in coarser fractions.

5.2 - pH

All the soil horizons sampled in the area have a tendency to acidity, the pH in H2O never reaches neutrality(tab. 5.1a,b). In general, differences between trends (fig. 5.2a,b,c) in the values measured in H_2O and KCl are not relevant: as expected from theory (Ministero per le Politiche Agricole, 1999), KCl measurements represent a smoother curve more adequate to detect general trends instead of peculiar conditions of the single horizon. The values of pH in H_2O tend to a mean pH of 5 which, in the case of KCl, become approximately pH 4. For both values measured in H_2O and in KCl, there is very little deviation from the average: in fact, the pH neither gets large variations between successive horizons nor within the entire depth of profile. This indicates a rather developed acidity that may be due both to soil forming processes and to the nature of parent material.

In many profiles (such as FG13/15, FG13/27, FG13/28, F14/02, F14/13, FG14/21, FG14/32, FG14/46 and FG14/47) pH values progressively increase with depth, approaching to the parent material, though in many cases this variation seems very moderate, being rarely more than 1 point of pH. This could be related to a progressive leaching of the soil cations, as can be seen from the exchangeable bases treated below.

Nevertheless, in some soils can be detected instead a decrease in pH with depth. This is always the case of profiles belonging to the paleosurface and it is related to the stratigraphy of this landform. In fact, from the top to the base of the colluvial unit, pH usually assumes a nearly constant value or a decreasing trend, while pH becomes suddenly more acid with the transition to the buried unit: this is clearly visible for example in profiles F13/04, F13/05 and F13/06 while in profiles F13/10 and F13/12 this passage is more gradual but still identifiable. This effect can be attributed by the action of different processes on the different units through time.

Finally, the value of pH in NaF was measured on sample profiles

Tab. 5.2 - pH in NaF values for the studied profiles. The horizon above the threshold level for andic properties (9,4) is highlighted.

Profile	Horizon	pH (NaF)
F13/04	A1	8,12
	A2	8,63
	AB	8,72
	B	8,86
	2Ab	8,50
	3Bt	9,22
	3BC	8,77
F13/05	A1	8,46
	A2	8,51
	2Ab	8,30
	3Bw	9,30
	3Bt	9,67
	3BC	9,29
F13/06	O	7,52
	A1	8,52
	A2	8,79
	AB	8,34
	2Ab	8,47
	3Bt	9,36
	3CBg	9,20
F13/08	A1	8,37
	A2	8,44
	AB	8,93
	2Bt	8,23
	2BCg	8,34
F13/10	O	8,28
	A1	8,95
	A2	8,82
	AB	9,03
	2Bw	8,91
	3Bt	8,90
	3Btg	9,10
	3BtC	9,30
F13/12	A1	8,21
	A2	8,59
	AB	8,20
	2Bw1	8,61
	2Bw2	8,52
	3Bt1	9,21
	3Bt2	9,34

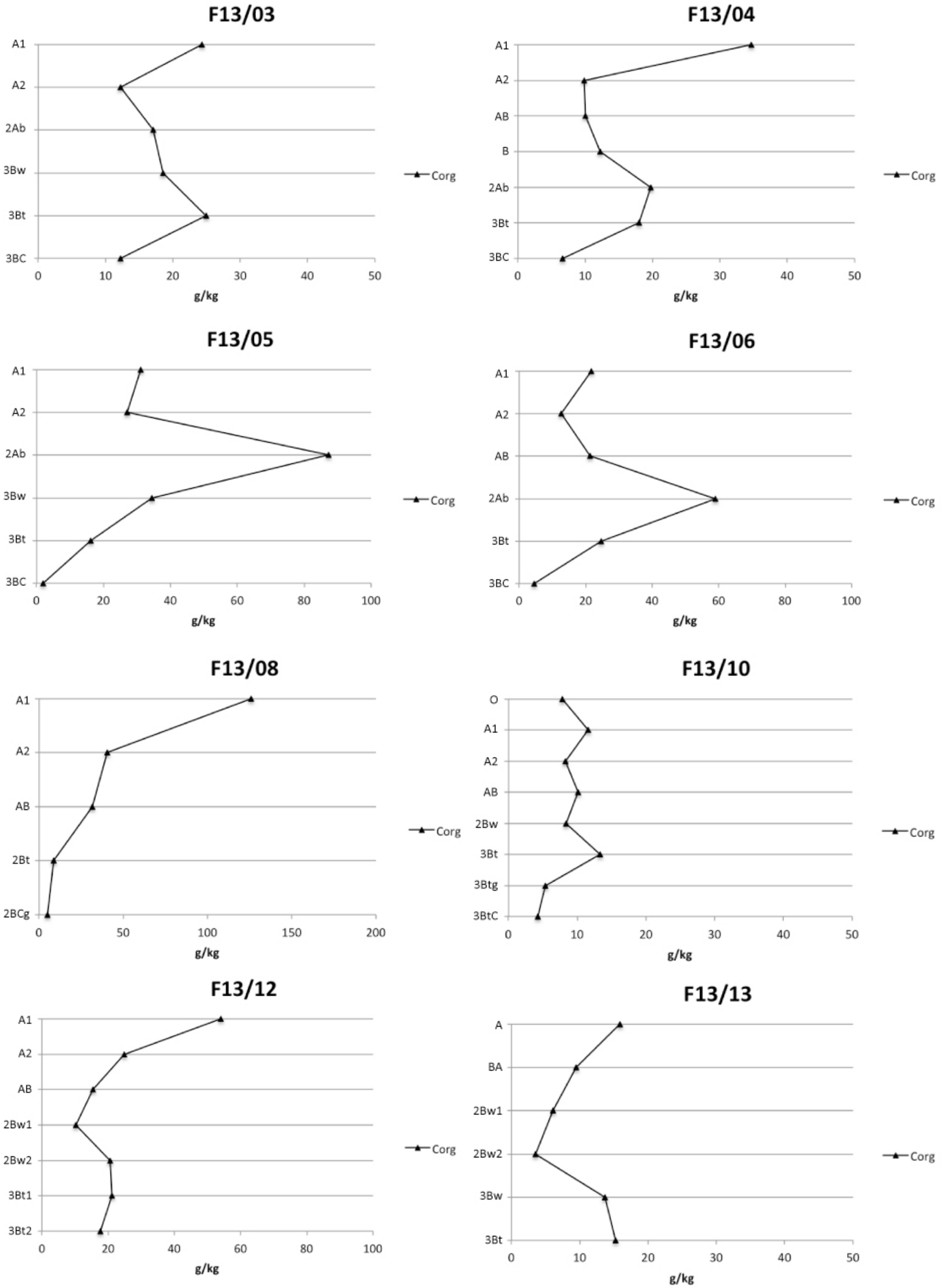

Fig. 5.3a - Organic carbon content of the studied profiles

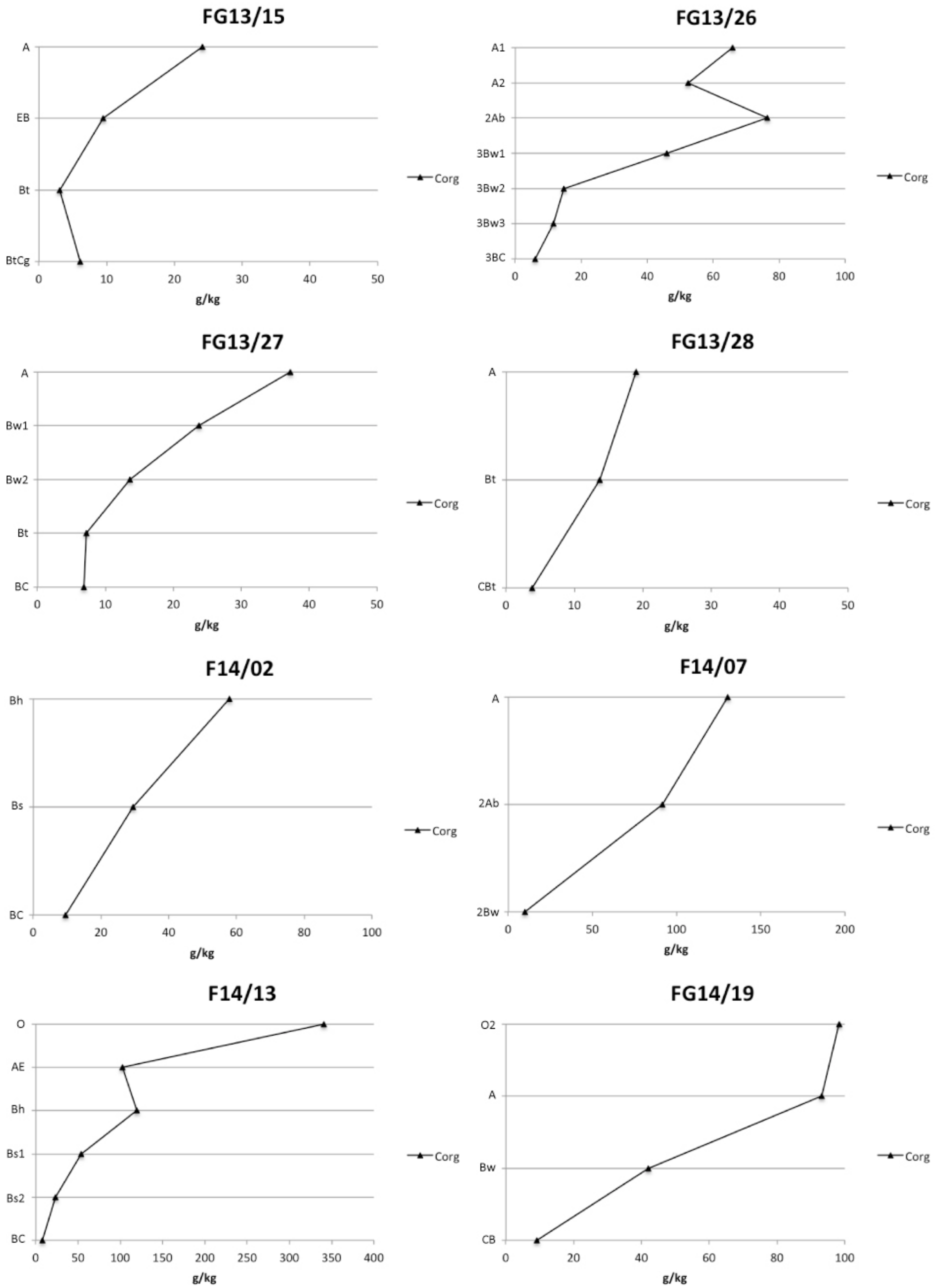

Fig. 5.3b - Organic carbon content of the studied profiles - continued

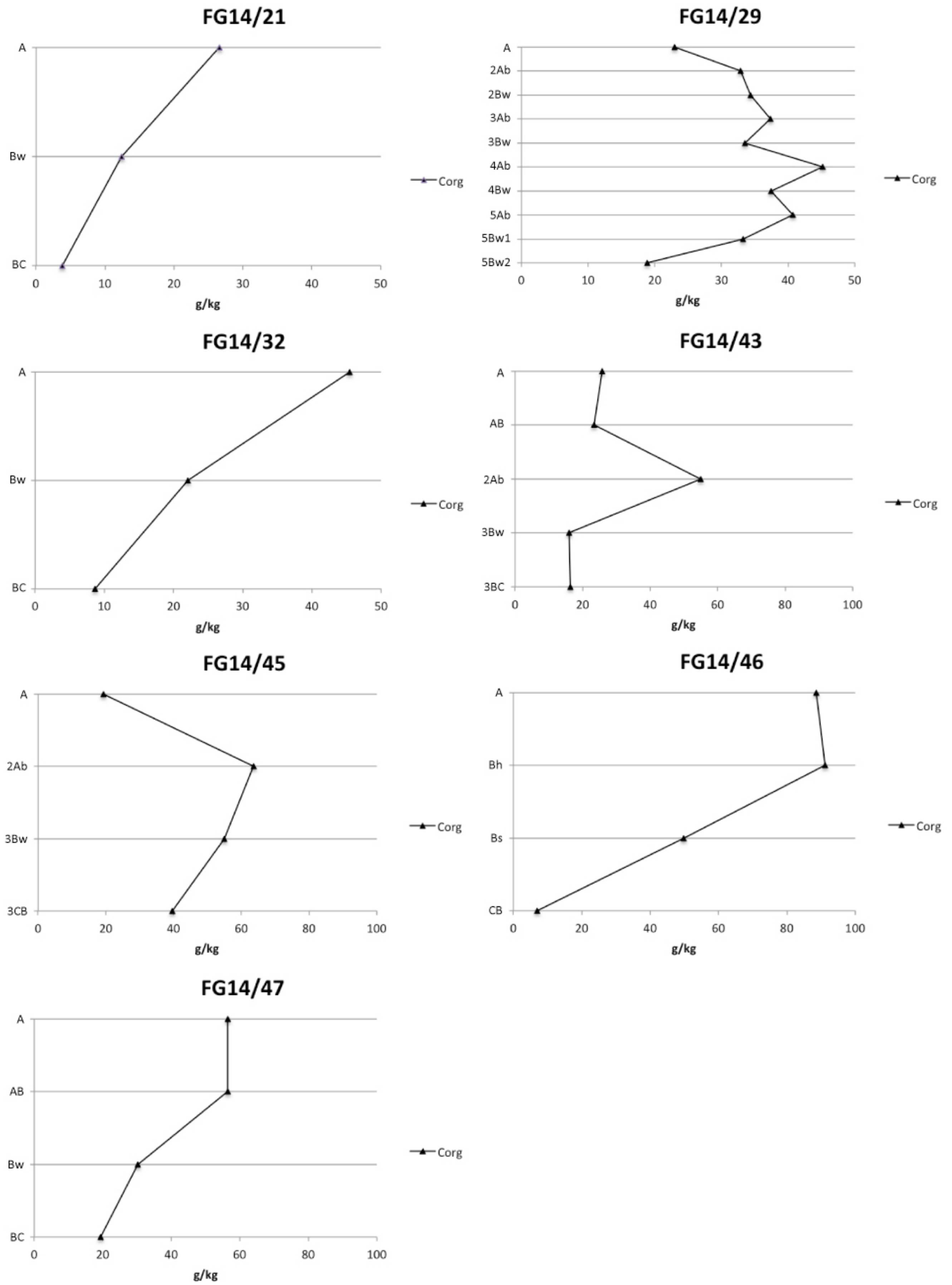

Fig. 5.3c - Organic carbon content of the studied profiles - continued

belonging to the paleosurface in order to verify the presence of allophane and thus andic properties (FAO, 2014). None of the results except one (profile F13/05, 3Bt horizon) reach the threshold value of 9.4 thus excluding the presence of these properties (tab. 5.2).

5.3 - Organic carbon

Organic carbon curves show a series of well-defined patterns in all profiles studied. The absolute quantities are very variable depending on the type of profile and depth (tab. 5.1a,b). In surface horizons, values ranging between 20 and over 200 g/kg can be found: these values decrease with depth and usually get below 20 g/kg at the base of the profile. In this light, the general trend (fig. 5.3a,b,c) is therefore represented by a decrease of organic carbon content as horizons get deeper: this decrease can be more or less gradual, as in profile FG13/27, or concentrated as a rapid loss at the transition from the uppermost horizon to the ones those below, such as in profile F14/08.

There are exceptions to the above described trend: as regards the profiles sampled on the paleosurface, a peak in the organic carbon content is often found, corresponding to a specific horizon (in many cases 2Ab), while in the horizons underlying it the values return to decrease. Sometimes, peaks in organic carbon are more than one (F13/10 and FG14/29). This behaviour is essentially linked to the presence of soil/paleosol sequences: in fact, the organic carbon peak is mainly corresponding to uppermost horizon belonging to a buried paleosol sequence. The amount of organic carbon measured in these horizons is often comparable to surface horizons, if not sometimes much higher (F13/05).

An exception to this general rule is represented by profile F14/13, which shows the typical behaviour of a podzol with accumulation of organic matter in the Bh horizon. Profile F13/12 is also an exception, but in this case the opposite occurs and the peak appears one horizon below the uppermost the paleosol: as seen from particle size analysis, this uppermost 2Bw horizon shows features more similar to the colluvium above than to the paleosol below.

5.4 - Iron extractions

The presence of iron inside soils follows a series of different trends (tab 5.1a,b) which can easily be described as follows. Total iron (Fe_{tot}) is generally attested around 4-5% of the total mass of the soils, which is in line with geochemical literature (Cornell and Schwertmann, 2003). In few cases, represented by profiles F14/02, FG14/19 and FG14/29, this value is reduced, reaching 1-2%. Moreover, total iron usually tends to slightly increase in the more developed horizons (fig. 5.4a,b,c), but this is not a general rule, and sometimes positive and negative peaks can appear in less obvious positions (e.g. F13/04, F13/05 and F13/13). These discontinuities are generally linked to possible accumulation or depletion of iron in the profile or to the presence of different soil units: in soils belonging to the paleosurface total iron is generally higher inside he buried units compared to the

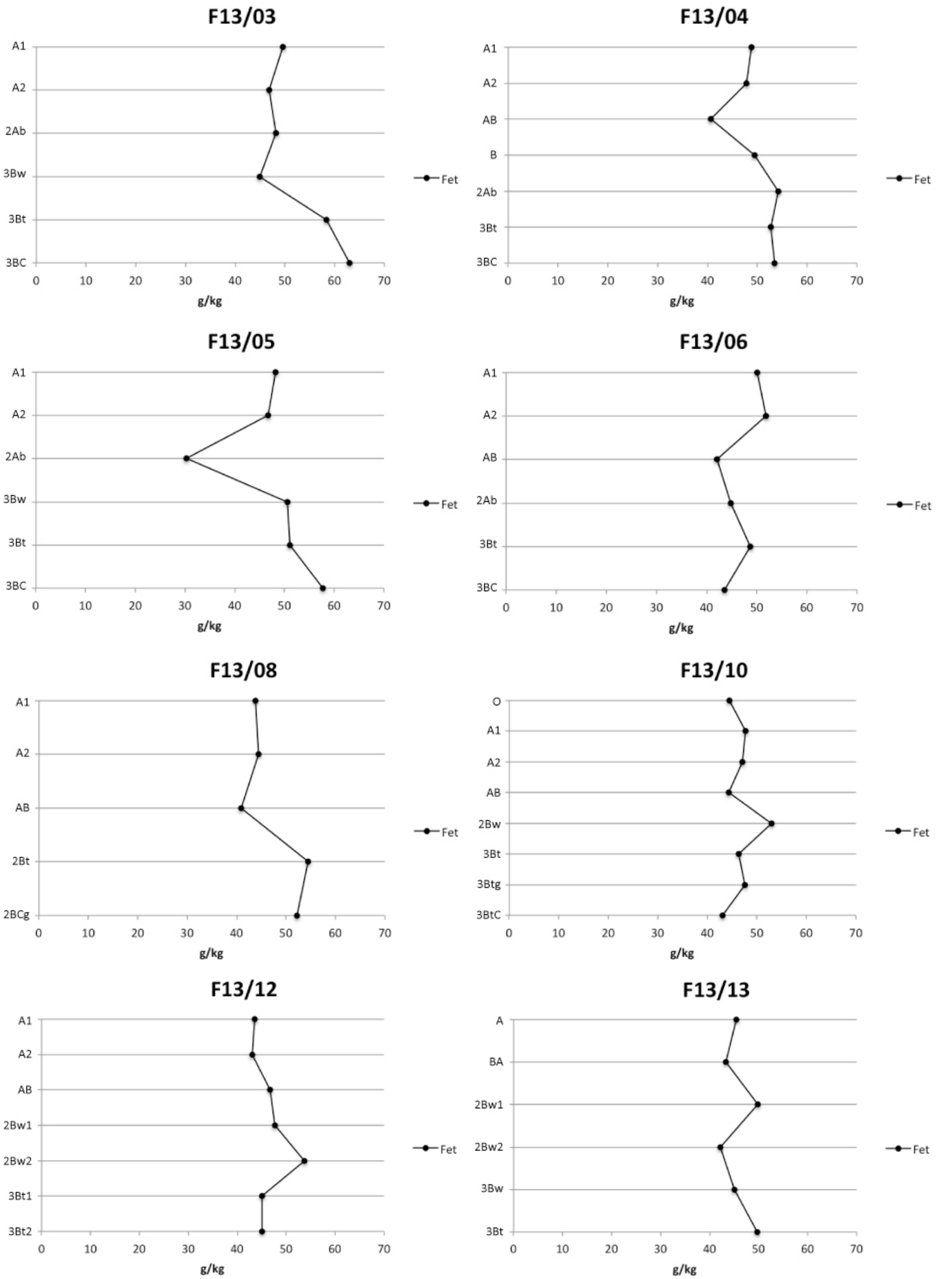

Fig. 5.4a - Total iron content of the studied profiles

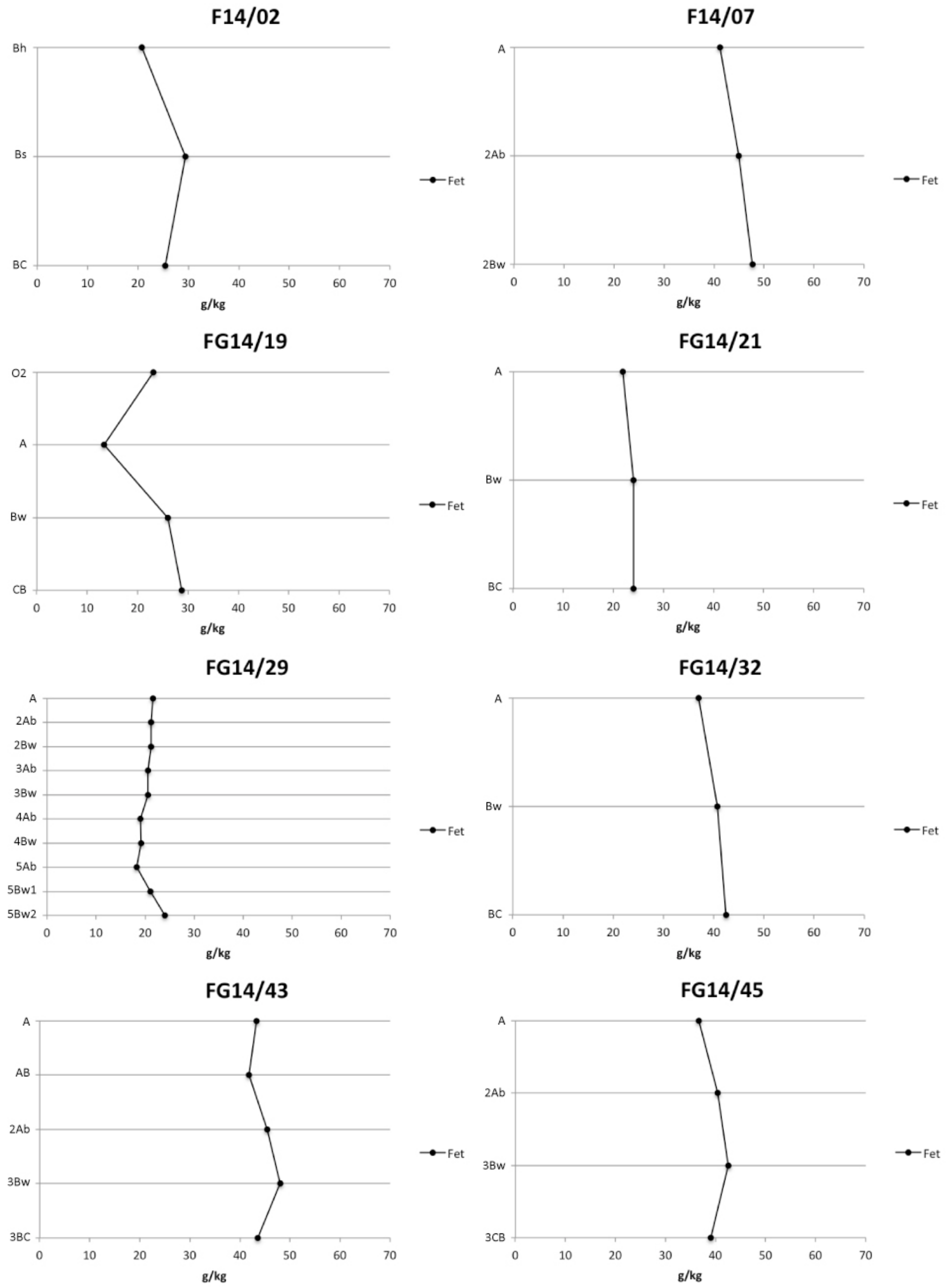

Fig. 5.4b - Total iron content of the studied profiles - continued

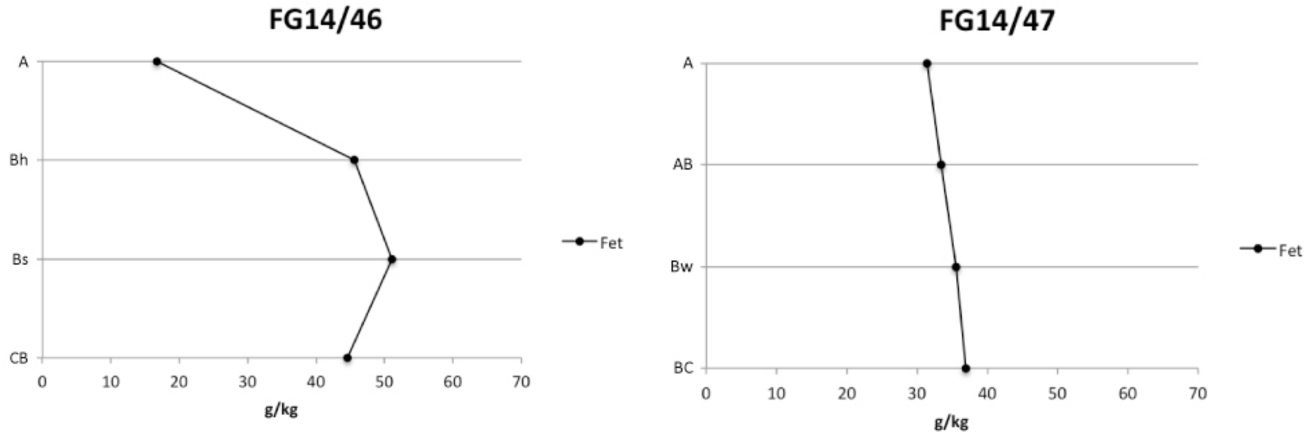

Fig. 5.4c - Total iron content of the studied profiles - continued

colluvial unit above (with the exception of profile F13/06).

Total amount of free iron (Fe_d) inside a single horizon can reach up 40 g/kg, but usually this value is limited to 10-20 g/kg in most horizons. Amorphous iron (Fe_o) is less represented, being around 5-10 g/kg in the majority of horizons measured. Together with these data, crystalline iron was calculated as difference between the two iron forms (Fe_d-Fe_o). It can be seen (fig. 5.5a,b,c) that in many cases this is more represented than amorphous iron, but still mainly under 10 g/kg. Amorphous iron is instead more abundant than crystalline in many buried units of the paleosurface (F13/04, F13/05, F13/06, F13/12) and in profiles F13/08, F13/26, F14/13 and F14/19, as well as inside B horizons of other soils. This prevalence of amorphous on crystalline iron could mean a prevalence of redoximorphic features in these profiles, or of a podzolisation - like process in the case of profiles F14/13 and F14/19.

Free and amorphous iron seem to be closely related since they share mostly the same trends in the studied soil profiles. The same cannot be said for crystalline iron, which often follows trends opposite to those of amorphous iron (e.g. F13/06, F13/10, F14/07 and FG14/29). In some cases (F13/03, FG13/15 and FG14/46 in particular) these iron forms simply tend to increase with depth and it are related to the actual presence of the most developed horizons at the bottom of the profile. In other profiles (e.g. FG13/28, FG14/32, FG14/43 and FG14/45) there is no significant trend and values are constant for the whole profile. A completely different trend is present when a peak in iron content is present into intermediate horizons: this is the case of profiles F13/04, F13/05, F13/13, FG13/26 and F14/13 (among others) and it is related to the presence of well developed horizons (usually Bw, Bt, Bs, but also 2Ab). In some cases these peaks do not match in different iron forms, such as in the case of F13/06, F13/08, F13/10 and F14/29.

Iron indices show different values for soils (tab. 5.1a,b). The free/total iron ratio is usually between 20 and 40% in many of the soils studied. Peak values can reach 60% in deep buried horizons of the paleosurface, as well as up to 80% in some particular soils not belonging to the paleosurface (F14/02, FG14/19). Amorphous/free ratio varies between 30 and 50%; buried paleosols can have values up to more than 70% in single horizons, while the highest peaks are in profile F14/13 where this index reaches 80%. There are also lower values, as for example FG13/15 and FG13/28, which never

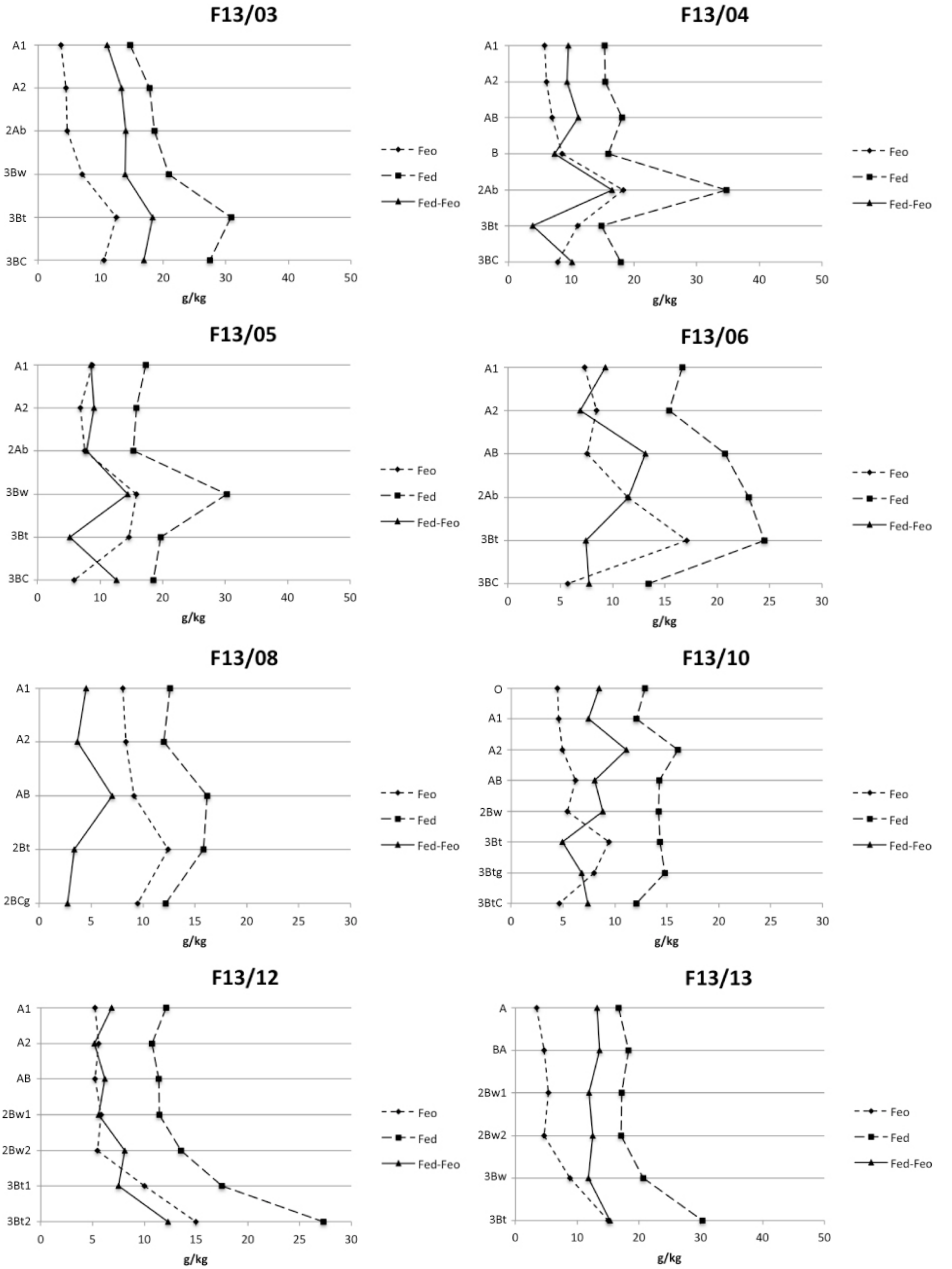

Fig. 5.4a - Free (Fed), amorphous (Feo) and crystalline (Fed-Feo) iron content of the studied profiles

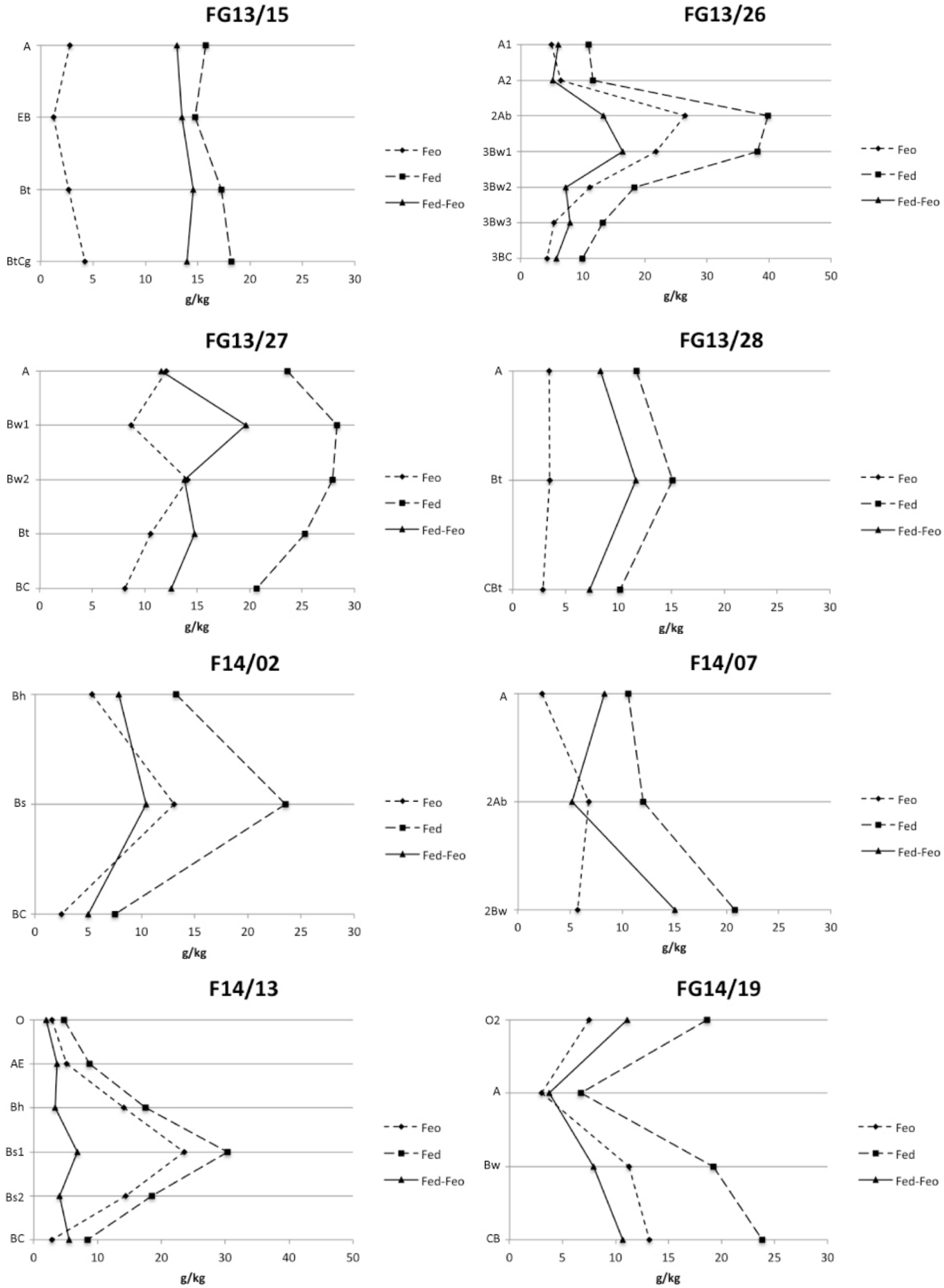

Fig. 5.4b - Free (Fed), amorphous (Feo) and crystalline (Fed-Feo) iron content of the studied profiles - continued

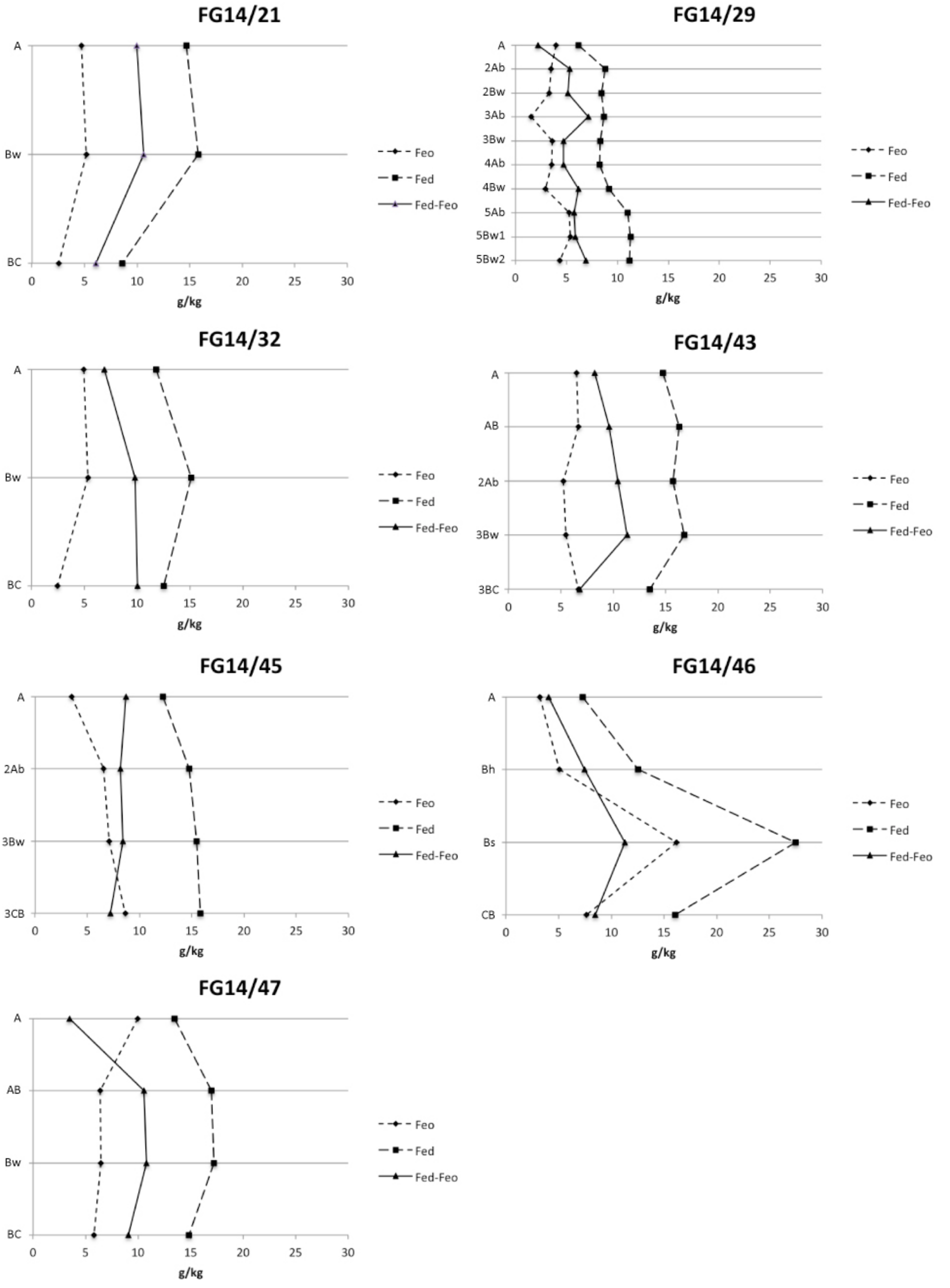

Fig. 5.4c - Free (Fed), amorphous (Feo) and crystalline (Fed-Feo) iron content of the studied profiles - continued

reach 30%. The weathering index often stays on values between 10 to 30%. This value is higher in some particular profiles which basically correspond to many of the buried units of the paleosurface, but even there it reaches maximum values around 40% in the more developed horizons without getting higher.

5.5 - Exchangeable bases

These analyses were conducted only on the 6 paleosurface sampled profiles (tab. 5.3). The values of cation exchange capacity (CEC), which express the amount of exchangeable cations in the soil, are quite low from a soil fertility point of view, and usually stay between 10 and 20 cmol$^+$/kg. Only some horizons, especially surface and 2Ab horizons possess higher values, with the latter reaching values over 40 cmol$^+$/kg. These highest values are correctly measured inside horizons rich in organic matter and therefore with more affinity for cation exchange. The results of the exchangeable bases ($Ca2^+$, $Mg2^+$, K^+ and Na^+) clearly show a depletion of cations from the soils. The quantity of total bases present in all the sampled horizons is very limited, especially for magnesium and potassium, both below 1 mg/kg in every horizon; concentration of calcium is slightly higher nearest to the surface, where it can reach 2 mg/kg, while sodium is more abundant and stays on average on 4-5 mg/kg. In particular, sodium concentration is also the only constant one within each single profile, while for the other three it decreases with depth.

Tab. 5.3 - CEC, exchangeable bases and BCSR values of the studied profiles.

Profile	Horizon	CEC cmol(+)/kg	K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	BCRS %
F13/04	A1	20,28	0,71	2,06	0,25	4,69	38,02
	A2	16,48	0,49	1,41	0,16	4,69	40,97
	AB	11,68	0,51	1,32	0,15	5,21	61,58
	B	16,29	0,47	0,74	0,08	4,63	36,33
	2Ab	28,89	0,47	0,60	0,04	4,53	19,52
	3Bt	25,34	0,43	0,47	0,03	4,62	21,90
	3BC	17,58	0,49	0,59	0,05	4,75	33,45
F13/05	A1	24,66	0,61	2,13	0,19	4,63	30,66
	A2	23,93	0,50	2,25	0,13	4,53	30,97
	2Ab	48,63	0,49	2,06	0,08	4,64	14,95
	3Bw	39,30	0,46	0,78	0,03	4,64	15,04
	3Bt	28,59	0,44	0,48	0,02	4,43	18,78
	3BC	22,02	0,44	0,41	0,02	4,27	23,34
F13/06	O	16,45	0,82	1,96	0,45	4,71	48,26
	A1	11,43	0,61	0,73	0,13	5,20	58,36
	A2	13,81	0,50	0,76	0,13	4,89	45,47
	AB	18,60	0,31	0,50	0,11	4,70	30,22
	2Ab	42,15	0,32	0,38	0,06	4,80	13,19
	3Bt	24,93	0,33	0,17	0,02	5,01	22,18
	3CBg	13,70	0,31	0,13	0,03	4,60	37,02
F13/08	A1	-	-	-	-	-	-
	A2	9,63	-	-	-	-	-
	AB	18,82	-	-	-	-	-
	2Bt	2,56	-	-	-	-	-
	2BCg	11,79	-	-	-	-	-
F13/10	O	18,19	0,67	2,33	0,25	4,73	43,86
	A1	13,03	0,53	1,86	0,16	4,66	55,33
	A2	11,42	0,52	1,82	0,16	4,62	62,36
	AB	12,18	0,52	1,68	0,15	4,64	57,37
	2Bw	11,87	0,48	1,51	0,13	4,40	54,95
	3Bt	16,05	0,50	1,55	0,14	4,54	41,93
	3Btg	11,93	0,50	0,50	0,04	5,36	53,64
	3BtC	10,35	0,52	0,50	0,04	5,27	61,18
F13/12	A1	27,92	-	-	-	-	-
	A2	17,71	-	-	-	-	-
	AB	17,75	-	-	-	-	-
	2Bw1	16,69	-	-	-	-	-
	2Bw2	20,29	-	-	-	-	-
	3Bt1	20,44	0,30	1,47	0,05	4,60	11,15
	3Bt2	12,23	0,30	1,29	0,04	4,70	17,16

From CEC and exchangeable

cations for each horizon, the base-cation saturation ratio (BCSR) can be calculated (Ministero per le Politiche Agricole, 1999), which in general shows low values: for example F13/05 is never above 30%, while other profiles tend to stay between 30 and 60%. Being this essentially a measure of soil fertility, comparison charts put these values among mostly infertile soils (Perelli, 1985). However, it still gives some information about soil behaviour as a non-agronomic case study: BCSR in these soils is inversely related to CEC, since total exchangeable cations concentration is very low. Thus not only soil horizons are mainly unsaturated, since depleted cations are not being replaced, but this effect is further enhanced in presence of organic horizons, where cation depletion is paired with a higher CEC caused by the high amount of organic matter present.

Tab. 5.4 - Total N and exchangeable P values of the studied profiles.

Profile	Horizon	N (g/kg)	P (mg/kg)
F13/04	A1	3,12	29,92
	A2	1,28	29,85
	AB	1,02	19,99
	B	1,16	19,90
	2Ab	6,16	68,82
	3Bt	1,61	20,15
	3BC	0,98	21,06
F13/05	A1	2,62	29,68
	A2	2,39	22,22
	2Ab	5,62	40,80
	3Bw	3,06	24,71
	3Bt	2,05	22,14
	3BC	1,20	18,57
F13/06	O	4,12	41,63
	A1	1,70	25,08
	A2	0,63	18,48
	AB	1,92	19,15
	2Ab	5,26	45,12
	3Bt	2,35	24,98
	3CBg	0,77	24,48
F13/08	A1	-	-
	A2	3,60	64,86
	AB	3,70	55,10
	2Bt	2,32	39,14
	2BCg	1,50	43,70
F13/10	O	2,06	19,40
	A1	0,85	22,73
	A2	0,71	22,72
	AB	0,48	14,93
	2Bw	0,81	17,82
	3Bt	1,10	16,65
	3Btg	0,60	24,31
	3BtC	0,73	26,64
F13/12	A1	3,14	606,73
	A2	1,98	33,33
	AB	1,19	18,74
	2Bw1	0,94	20,07
	2Bw2	1,67	21,15
	3Bt1	2,13	32,84
	3Bt2	1,80	26,70

5.6 - Nitrogen and phosphorus

The results of total nitrogen and phosphorus measurement obtained from paleosurface profiles (tab. 5.4) are consistent with other analyses, especially organic carbon content, as they define the presence of different soil units. The presence of a distinct peak at the interface between colluvial and buried units can be found in the 2Ab horizons of profiles F13/04, F13/05 and F13/06. Moreover, these peaks have the highest value of the profile, even considering the surface horizon: As expected, N and P are positively influenced by the presence of organic matter. In profile F13/12 these chemical parameters reach their highest in the superficial horizons, decrease in the intermediate unit and grow again with the passage to the lowest unit; profile F13/08 shows instead a more or less constant decrease for these elements with depth. F13/10 is more difficult to explain since here N and P follow in this case contrasting trends.

5.7 - Clay mineralogy

The main components of the clay size fraction of soil profiles sampled on the paleosurface (fig. 5.5a,b) are illite (I), quartz (Q) and chlorite (Chl), with illite bearing the highest peaks, followed by quartz; chlorite shows only minor peaks. Mixed layer clays (MLC) appear frequently, with better expressed peaks in the buried units and less expressed near the surface. Iron hydroxides also appear in the buried units (and in the O horizon of profile F13/10, indicating possible inheritance of paleosol

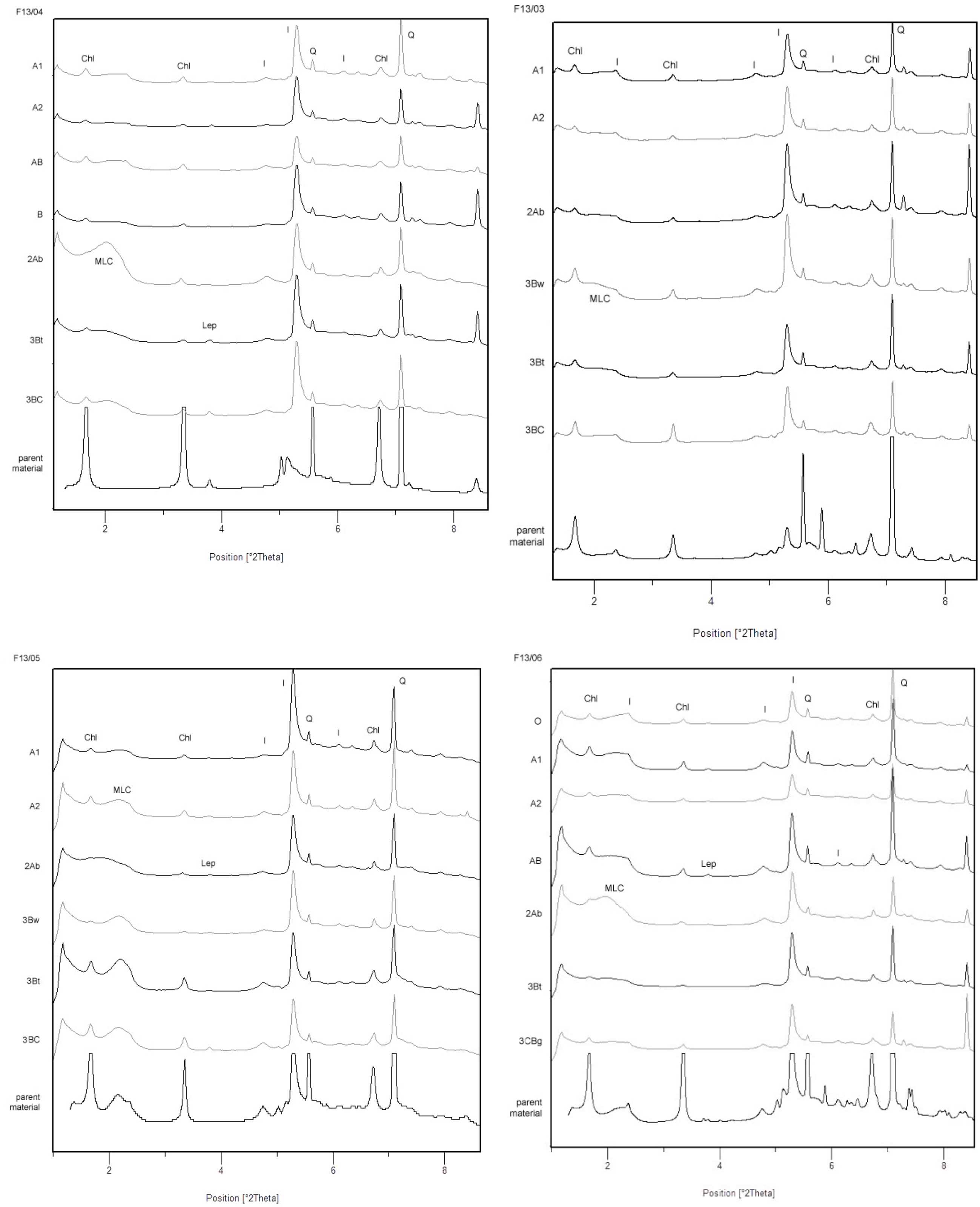

Fig. 5.5a - Mineralogy of the clay fraction of the studied soils: Q - quartz; Chl - chlorite; I - illite; MLC - mixed layer clays; Lep - lepidocrocite.

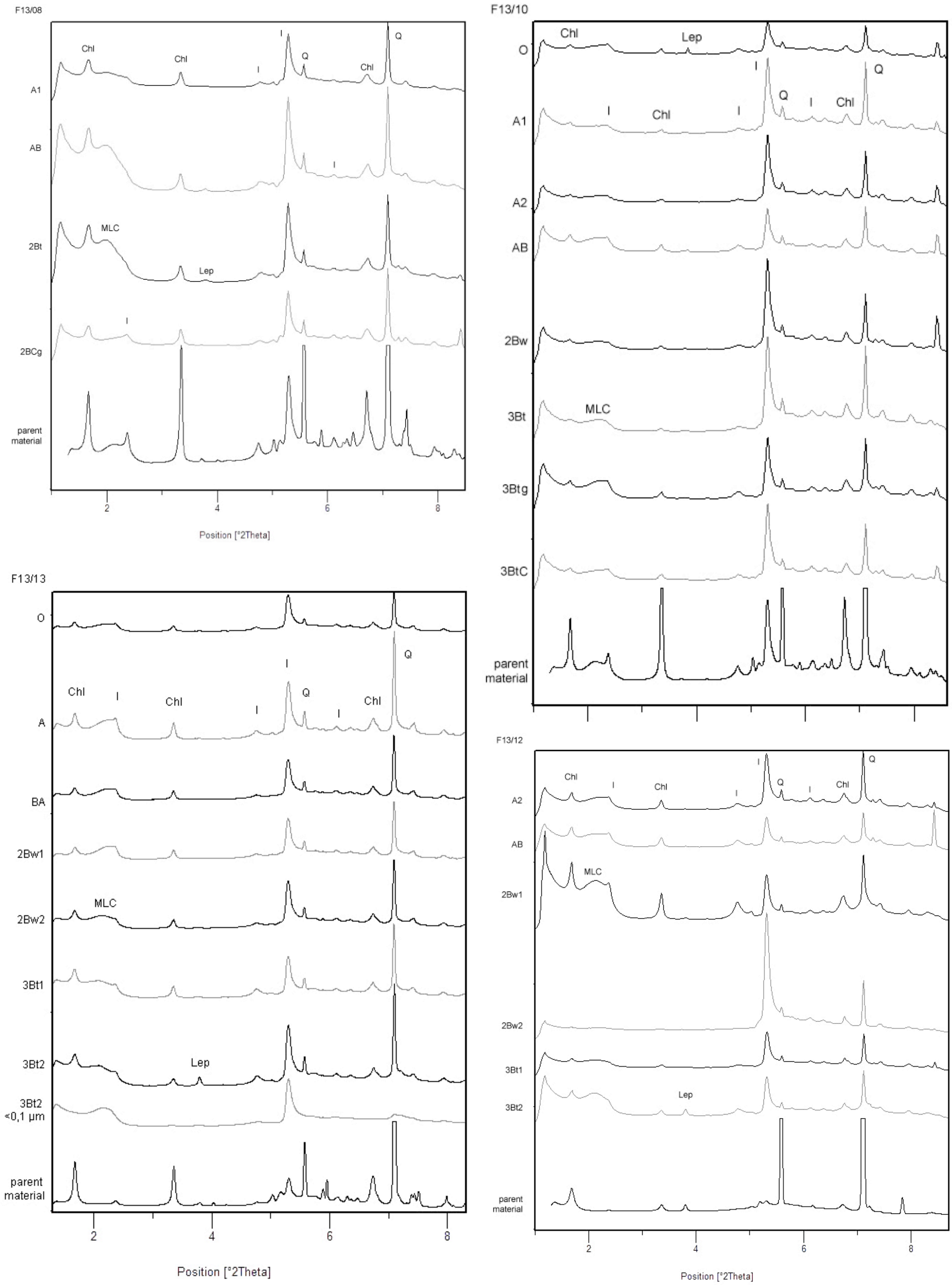

Fig. 5.5b - Mineralogy of the clay fraction of the studied soils - continued

material inside the colluvium) in the form of lepidocrocite (Lep).

Differences in parent material aren't related to a different mineralogy, but to different proportions of the same minerals: in parent material samples quartz and chlorite are the principal minerals, with illite mainly as an accessory and almost no mixed layer clays (completely absent in profiles F13/03, F13/04, F13/12 and F13/13).

To better understand the nature of these clays as inherited or neoformed, a tentative measurement on the fine clay fraction (lower than 0.1 µm) was carried out on the 3Bt2 horizon of profile F13/13, as neoformed clay tends to concentrate inside the finer size classes (Wilson, 1999; Tabor et al., 2002; Vitali et al., 2002). The result shows how in this fraction quartz and chlorite completely disappear, leaving only illite and mixed layer clays as the main minerals present.

Chapter 6

Micromorphological characterisation

Micromorphological descriptions (see appendix 2) and interpretations of soil thin sections were mainly conducted on the paleosurface profiles or, in general, on soils presenting multiple pedogenetic units, in order to better characterise the formation of these soils in their different stages and to highlight the link between pedogenesis and the geomorphic processes involved.

6.1 - Mt Bagioletto

Five soil profiles belonging to the flat area of paleosurface placed S of Mt Bagioletto were analysed (F13/03, F13/04, F13/05, F13/06 and F14/07). These soils are characterised in the field by a series of common features (see chapter 4), among which the most evident of all is the presence of a 2Ab horizon which separates the colluvial unit at the top from the buried sequence at the base of the profile, which is generally composed of (3Bw) - 3Bt - 3BC horizons. Together with these soils, the A horizon of the profile FG14/19 located on the N side of Mt Bagioletto was described for comparison purpose with the 2Ab horizons of the paleosurface profiles.

In the upper unit, the main constituents of the fabric are weakly sorted coarse rock fragments (fig. 6.1a). Allocthonous soil rounded fragments (i.e. pedorelicts *sensu* Brewer, 1976) with a higher degree of pedogenesis are other recurring elements of the upper unit (fig. 6.1b). They can be found isolated or represent the dominant fabric unit in the groundmass, as in the case of profiles F13/04 and F13/06. In the second case, their morphological characteristics are similar to those of the buried unit horizons (e.g. F13/05 3Bw; fig. 6.1c). Proportions between these two main components vary at different depths and profiles, forming various microstructures: intergrain microaggregate when rock fragments prevail, granular to subangular blocky (in AB horizons) in the other case. Fine material generally shows a brown or more grayish colour, with a speckled limpidity and a weak stipple speckled b-fabric. Porosity is high (voids are usually common or frequent) as an effect of both transport and biological activity (fig. 6.1d). Bioturbation is common, with passage features represented by fabric hypocoatings and matrix infillings (fig. 6.1e). Star-shaped vughs appear in the more developed AB horizons of profile F13/04. Other pedofeatures are quite rare, usually limited to small and possibly anorthic Fe–Mn nodules with sharp, rounded boundaries produced by transport. Fragmented clay coatings (i.e. papules *sensu* Brewer, 1976) are also present in profile F13/04.

In thin section, the deep unit is more complex than the upper one. The 2Ab horizon is micromorphologically characterised by a very fine granular microstructure (40–80 μm; fig. 6.1f) and a general scarcity of coarse constituents other than charcoal and nodules (fig. 6.1g). The most important features are related to porosity (fig. 6.1h), in particular the pattern of parallel-perpendicular planes, with the presence of vertical wedges at the upper interface in profile F13/04. In profile F13/05 this pattern of planes is expressed enough to form a secondary angular blocky microstructure. These planes are often superimposed on other features of the soil, especially Fe-Mn nodules and sometimes charcoals. Moreover, clayey pedorelicts with fabric similar to deeper horizons (e.g. F13/04 3Bt) are found in one of the biggest fissures (a few millimeters wide). Subrounded Fe–Mn nodules with sharp boundaries are the other pedofeature of the 2Ab horizon. These features, and particularly the absence of coarse rock fragments, mark a strong discordance from both the upper unit and the rest of the buried unit. The A horizon of profile FG14/19, sampled as comparison in order to find similarities with the present day pedogenesis, shows a microstructure which is indeed similar, with the presence of the same granular aggregates as well as charcoals and Fe-Mn nodules, nevertheless the coarse mineral components are frequent, with a prevalence of weakly weathered quartz and sandstone grains and the parallel-perpendicular porosity patterns are absent (fig. 6.1i).

The 3Bw horizons sampled in the deep unit present a range of microstructures from granular/ blocky and rich in star-shaped vughs to more expressed blocky (fig. 6.1c). Fine material turns to a more reddish or yellowish colour and to a cloudy limpidity; b-fabric is better expressed, often granostriated or porostriated. Very few charcoal fragments are found in profiles F13/05, F13/06 and F14/07. Fe–Mn nodules share the same characteristics of the horizons below.

These features become more emphasised in the 3Bt horizons. Thin sections show blocky or channel microstructures usually with few or very few voids. Fine material shows a high degree of pedogenesis, with well-expressed reddish-brown or yellowish-brown colours and cloudy limpidity. B-fabric is usually striated and associated with argilloturbation (shrink and swell) features such as fabric hypocoatings (Stoops, 2003; fig. 6.2a,b). These b-fabric characteristics are lacking in profiles F13/04 and F13/06. The 3Bt horizons are in general rich in pedofeatures. Fe–Mn nodules occur more frequently (although they are always very few) and have different shapes, from subrounded or rounded to more irregular. Their shape changes from one profile to another but not at different depths within the single profile. Their boundary is in general more gradual than in the upper unit and in the 2Ab horizons. Textural pedofeatures show high variability in many profiles. Clay coatings are found in every profile. Microlaminated ones (fig. 6.2c,d) are always present in the lowest part of the profiles. Nonlaminated coatings (fig. 6.2e,f; absent in profile F13/03) are located above them or at the same

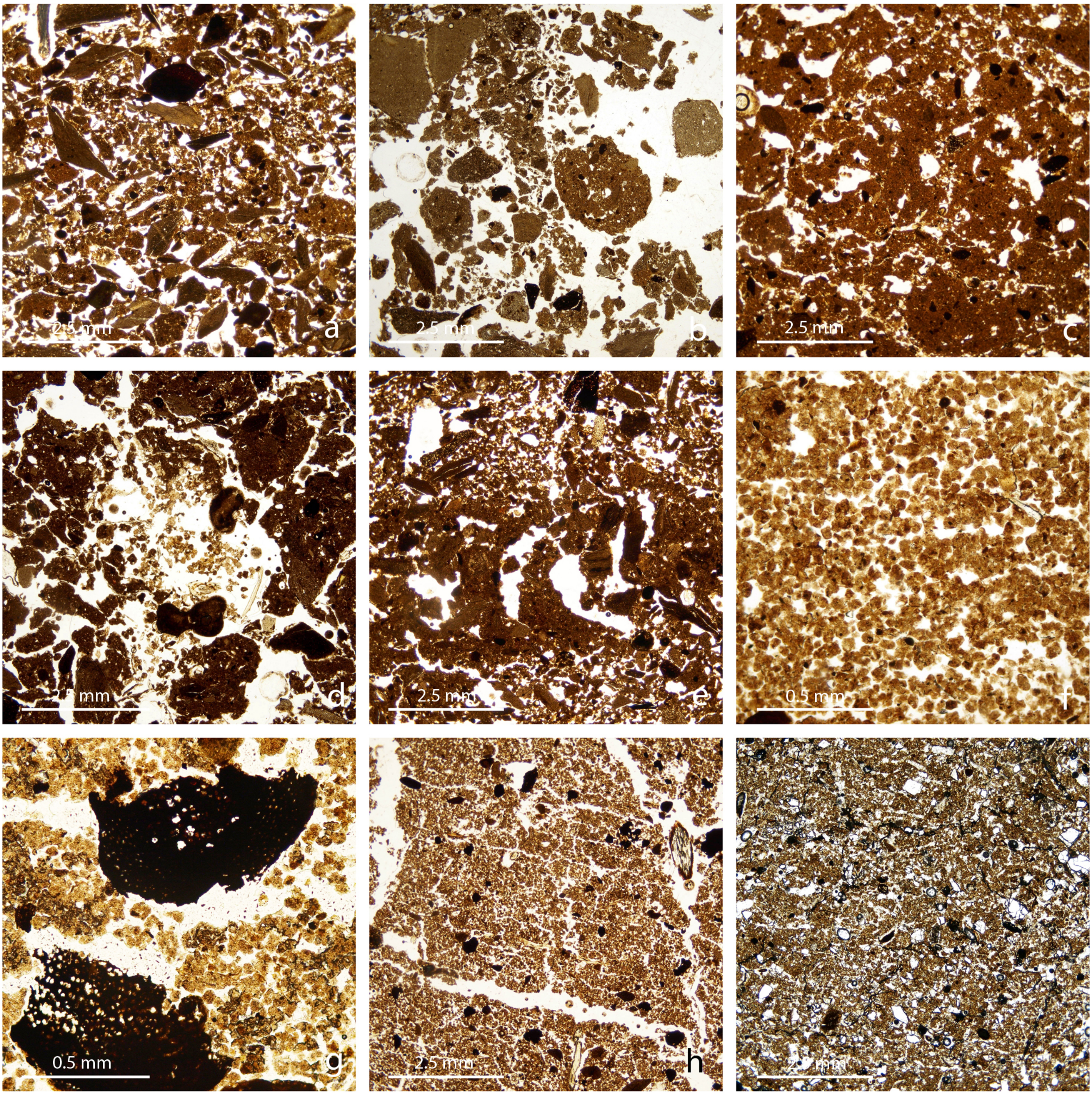

Fig. 6.1 - a) coarse rock fragments in A horizon (F13/04 - 20x, PPL); b) pedorelict mixed in the groundmass of AB horizon (F13/04 - 20x, PPL); c) blocky microstructure of 3Bw horizon (F13/05 - 20x, PPL); d) excrements infilling in a channel in A horizon (F13/06 - 20x, PPL); e) passage features inside BA horizon (F13/04 - 20x, PPL); f) fine granular microstructure of 2Ab horizon (F13/06 - 100x, PPL); g) charcoal fragments in 2Ab horizon (F13/05 - 100x, PPL); h) parallel-perpendicular planes in 2Ab horizon (F13/06 - 20x, PPL);i) coarse mineral grains and granular aggregation in A horizon (FG14/19 - 20x, PPL).

depth of the profile, but never below. Nonlaminated coarse coatings also appear in profiles F13/04 and F13/06, always located in horizons above fine coatings. In every thin section, at least part of the coatings has a gradual boundary with the groundmass: this can indicate a process of incorporation into the groundmass.

6.2 - Higher elevations

In this category two soils are present which still belong to the paleosurface though showing strong differences with the other profiles, mainly related to the higher altitudes and to the sandstone parent material.

Profile FG13/26 is located at an elevation of 2000 m on the N slope of Mt Cusna. It still retains the horizon sequence of the soils below, with the presence of a colluvial unit (not sampled for thin sections), a 2Ab horizon and a series of 3Bw horizons below. The 2Ab horizon has a more developed microstructure than the other soils, with local formation of a blocky structure (fig. 6.2g). The amount of coarse grains is also very different, reflecting the importance of the parent material: the section is in fact very rich in coarse quartz grains, as well as weathered sandstone fragments. This mineral composition does not change in the 3Bw horizon, but, in contrast, the microstructure becomes less expressed, with the presence of crumbs composed by compaction of loose material which also tends to form pellicles the coarser clasts (fig. 6.3a) Star shaped vughs also appear. This microstructure becomes even more extreme in horizon 3BC: the blocky structure disappears completely, leaving a microstructure composed by fine material coating the coarser sandstone fragments which are the major constituent of the soil mass. These coatings show evident signs of illuviation in the form of a granostriated b-fabric.

Profile FG14/29 is located on a stable flat location on the ridge crest more to the S, again at an elevation of about 2000 m. The main feature of this profile is the presence of 5 soil units, of which the second, third fourth and the top of the fifth are composed by the same Ab - Bw sequence: the 4Ab-4Bw-5Ab part of this sequence was sampled for micromorphological analysis together with the A horizon of the thicker colluvial unit above.

The two thin sections are similar to each other. The coarse fraction of the A horizon is mainly composed by fine sand clasts made of quartz, feldspars and weathered sandstone, sometimes with a rounded aspect (fig. 6.2h,i). The fine material, forming frequent granules is also present as well as bioturbation features such as channels, passage fabric pedofeatures and excremental pedofetures. The micromass is very weakly developed, with a speckled limpidity and stipple speckled b-fabric. The same microstructure and pedofeatures are present in the Ab and Bw horizons, with changes only in proportions: in both the granular fine material forms the majority of the groundmass and the coarse clasts are less frequent. The Ab horizons, other than having a darker colour than the rest of the soil, also show some features in common with 2Ab horizons from lower elevations, such as a pattern of parallel subhorizontal planes and the presence of charcoals into the groundmass (fig. 6.3b).

6.3 - Steeper areas of the paleosurface

These soils belong to different areas of the paleosurface characterised by a steeper slope and more active dynamics, which may have had an influence on their formation. F13/12 and F13/13 are

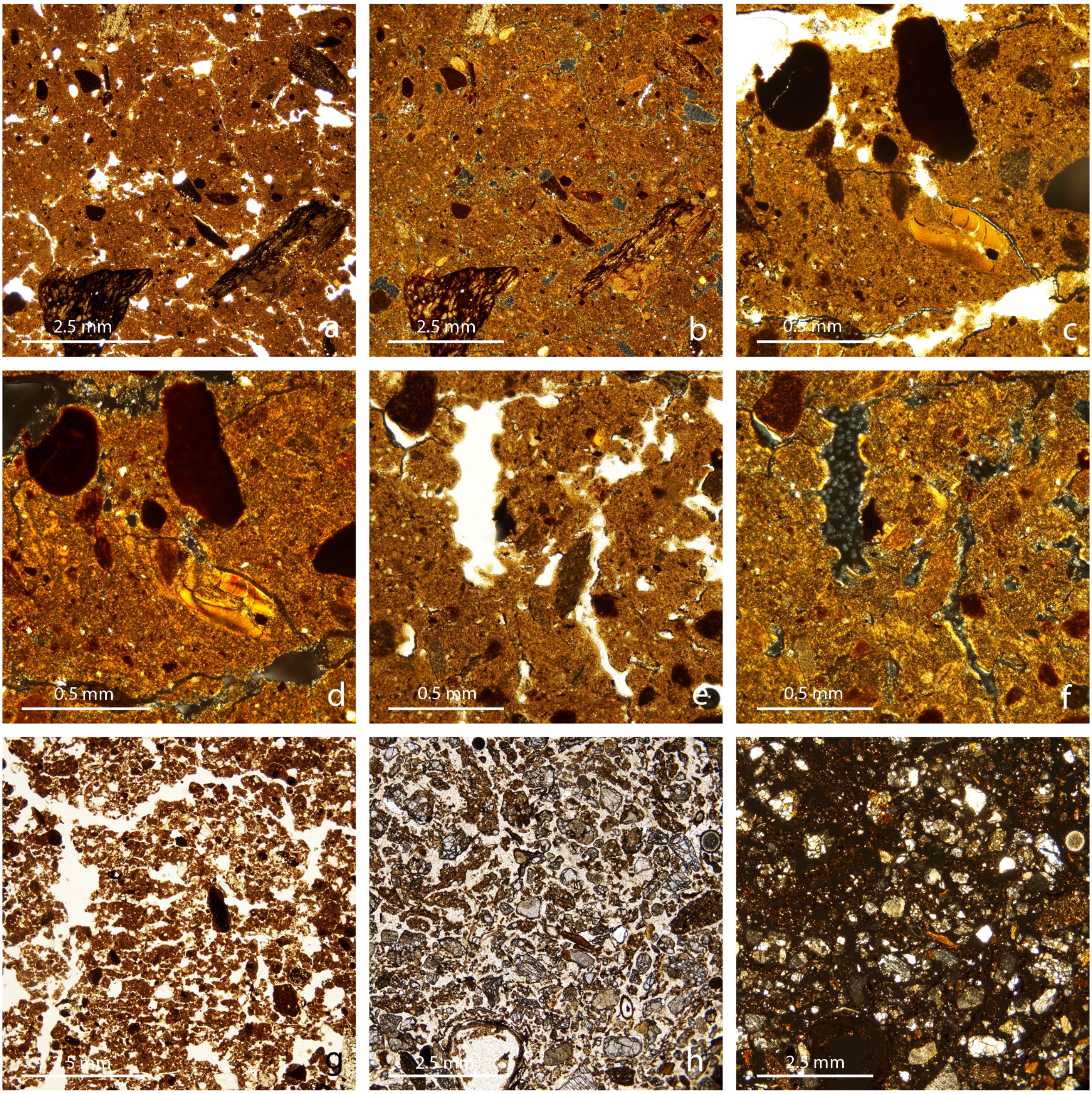

Fig. 6.2 - a) argilloturbation in 3Bt horizon (F13/03 - 20x, PPL); b) same as previous in XPL; c) microlaminated clay coating in 3Bt horizon (F13/05 - 100x, PPL); d) same as previous in XPL; e) nonlaminated clay coatings in 3Bt horizon (F13/06 - 100x, PPL); f) same as previous in XPL; g) blocky structure in 2Ab horizon (FG13/26 - 20x, PPL); h) coarse mineral grains inside A horizon (FG14/29 - 20x, PPL); i) same as previous in XPL.

located not far SE of the former soils closer to Le Prese. F13/10 and F14/36 belong to the NW slope of Mt Cusna, the former at lower altitude with respect to the latter. F13/08 is far from these soils, and was sampled on the NE slope of Mongiardonda in the southern part of the ridge. These profiles are composed by 2 or 3 soil units and lack of the 2Ab horizon already described for the paleosurface soils of Mt Bagioletto.

The upper unit shares many of the characteristics of colluvial units above described. In particular, the fabric characterised by variable proportions of weakly weathered clasts and pedorelicts is visible in all these profiles, whether forming an intergrain microaggregates or more granular-blocky microstructures. Profile FG14/36 for example shows an intergrain microaggregate microstructure with a horizontal orientation pattern in coarse clasts which can possibly indicate the presence of multiple colluvial depositions inside the unit. In profile F13/12 the microstructure is a well expressed blocky: here pedorelicts have been reworked into the soil mass, but are still visible thanks the presence locally

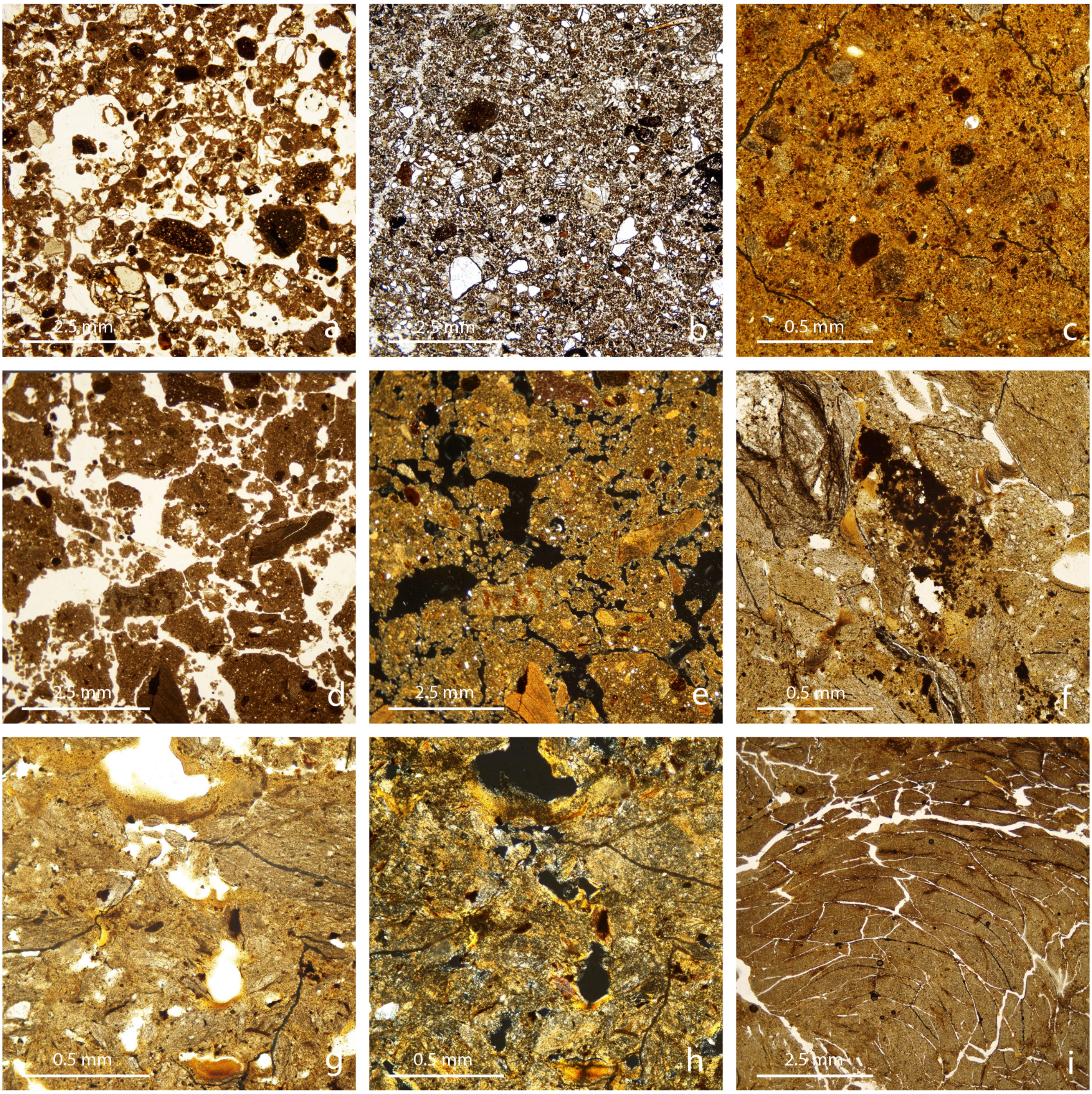

Fig. 6.3 - a) pellicles of fine material on coarse clasts 3Bw horizon (F13/26 - 20x, PPL); b) granular microstructure with coarse mineral fragments and charcoals in 4Ab horizon (FG14/29 - 20x, PPL); c) concentration of Fe-Mn nodules in 3Btg horizon (F13/10 - 100x, PPL); d) blocky microstructure in AB horizon (F12/13 - 20x, PPL); e) same as previous in XPL, with visible local striated b-fabric; f) aggregate Fe-Mn nodules in Bt horizon (FG13/18 - 100x, PPL); g) limpid clay coatings in Bt horizon (FG13/18 - 100x, PPL); h) same as previous in XPL; i) slickensides in BtCg horizon (FG13/18, 20x, PPL).

of a striated b-fabric (fig. 6.3d,e). Star-shaped vughs appear in the more developed AB horizons (e.g. F13/10 and F13/12). Papules are also present in profile FG14/36.

The intermediate unit is present in profiles F13/10, F13/12 and F13/13. It is characterised by a stronger degree of pedogenesis from the top unit in profiles F13/10 and F13/12, highlighted by a more expressed blocky structure and a more yellowish colour of the micromass. On the other hand, limpidity is speckled (as in the top unit) as well as b-fabric, which is stipple speckled though locally porostriated in profile F13/10. Pedorelicts are also present in both these profiles . Profile F13/13 shows instead an intergrain microaggregate microstructure and other features typical of colluvial units of the study area. All these features bring this intermediate unit to be considered as the overlying colluvium, i.e. as the oldest of multiple colluvial phases, which in some cases (F13/10) could have undergone a period of pedogenesis.

The unit at the base of the profiles is composed by well expressed Bt horizons sharing many of the characteristics already seen in flat areas. In particular, argilloturbation with related b-fabric is present in profiles F13/13 and F14/36, while microlaminated and nonlaminated clay coating are found in all profiles except for profile F13/13, where only nonlaminated are found. Profile F13/10, also shows a 3Btg horizon characterised a striated b-fabric associated with redoximorphic features: concentrations of Fe–Mn nodules (fig. 6.3c), pigmentations and Fe–Mn depletion hypocoatings. In profiles F13/08 and F13/13 this base unit is marked by a change in lithology of the coarse fraction. In the former the majority of the clasts are made of sandstones, instead of the claystones present in the overlying colluvium. In the latter the opposite happens, with claystones replacing sandstones.

6.4 - Forest soils

Two soils have been sampled at lower elevation and are related to a pedogenesis developed under a forest cover. These profiles, FG13/15 and FG13/18 located at the foots of Mt Cisa in the northern part of the map, are constituted of O - A - (EB) - Bt - BtCg horizon sequence, of which only the deepest horizons have been sampled.

The EB horizon (only present in profile FG13/15) shows a complex microstructure composed by the alternation of blocky peds and points where the micromass forms bridges or coatings on the coarse grains. The first microstructure is characteristic of B horizons, the second is reported for different E horizons (Wilson and Righi, 2010). Other characters of this horizon is the large amount of coarse clasts and the presence of alteromorphic nodules from strongly weathered organic material.

Bt horizons show a channel microstructure with low porosity; colour of the micromass varies between different shades of yellowish, lighter or darker brown. The b-fabric is extremely well expressed: it is generally striated, and in profile FG13/18 can locally become unistrial. Pedofeatures are represented by Fe-Mn nodules (locally aggregate in profile FG13/18; fig. 6.3f) and reorientation hypocoatings. Clay illuviation is scarce, but particularly well expressed both in thickness and limpidity

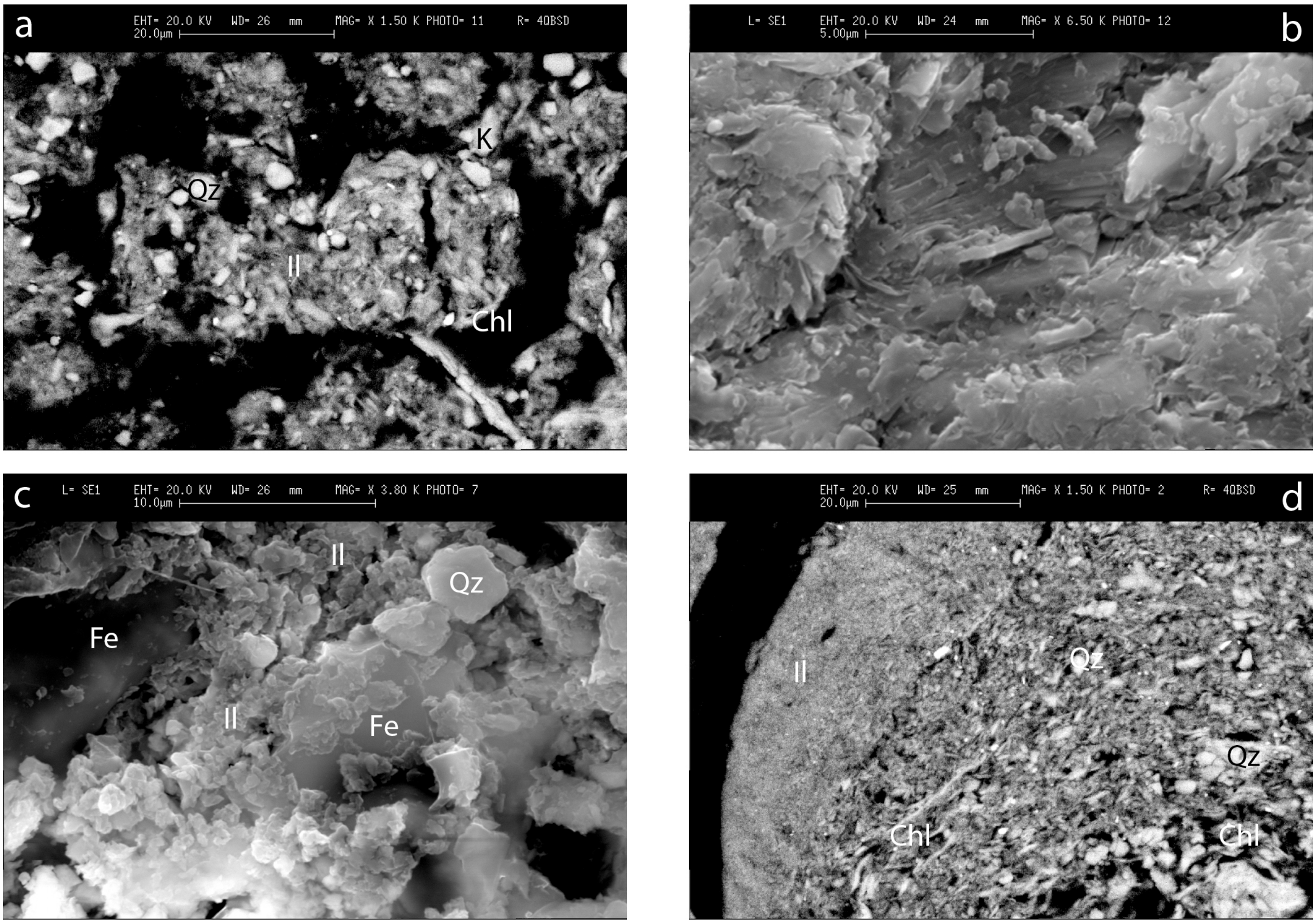

Fig. 6.4 - a) distribution of groundmass in 2Ab horizon (Qz - quartz, K - K-feldspar, Il - illite and mixed layer clays, Chl - chlorite); b) fragment of chlorite (center) inside Bw horizon; c) concentration of illite (Il) and quartz (Qz) around two iron nodules (Fe) in 2Ab horizon; d) clay and silt coating: the finer layer (left) is composed mainly by illite and mixed layer clays, the coarser layer (center) shows the addition of chlorite (Chl) and quartz (Qz) also present in the groundmass (right).

of coatings (fig. 6.3g,h). The Bt horizon of profile FG13/15 contains instead both coarser and finer coatings with evidences of incorporation into the groundmass.

The BtCg horizons of both profiles shows even stronger features: the groundmass consists of completely weathered claystone fragments inducing the differences in colour of the micromass and the striated b-fabric (as discussed by Stoops and Schaefer, 2010). Therefore, this horizon is not directly produced by pedoplasmation, but the result of a particularly strong weathering process of the saprolite which only locally shows microstructure and clay illuviation corresponding to the overlying Bt horizon. Moreover, in profile FG13/18 reorientation hypocoatings and slickensides (fig. 6.3i) are also present as well as aggregate Fe-Mn nodules and reddish iron hypocoatings, which are also visible as mottles in the field.

6.5 - SEM analysis

SEM observations allowed to give a better characterisation of certain aspects of the studied soils. In particular the finer groundmass and its main components were investigated. It can be seen as these are mostly the same recognised from clay size fraction mineralogy (fig. 6.4a): in fact the groundmass is mainly composed by a fine clay fraction matrix composed principally of 2:1 clays, in this case illite and mixed layer clays (Il). Inside and around this matrix, coarse fragments of quarts (Qz) and K-feldspars (K) can be found; chlorite (Chl) is also present in the form of coarser tabular fragments (fig. 6.4a,b). Iron oxides (Fe) are usually dispersed inside the finer part of groundmass, but in some cases can form more visible impregnations as large smooth nodules or coatings (fig. 6.4c). A closer look at clay illuviation shows that clay coatings are mainly formed by the finer fraction of clay (fig. 64.d), which again is composed by illite and mixed layer clays. Chlorite seems to be present only inside the coarser fraction of the coating, where tabular fragments are evident in smaller amount, or even absent.

Chapter 7

Soil development on Mt Cusna ridge: processes and factors

7.1 - Pedogenetic processes

It may be stated, with a certain degree of confidence, that pedogenesis in the study area started after the last glacial retreat, thus, all studied soils (including paleosols) belong to the Holocene. The traces of soil formation prior to the glacial times, completely disappeared during the glaciations. This was also affirmed in previous works (Panizza et al., 1982, Compostella et al., 2012) as the direct and indirect result of glacier action; however, a thorough observation on the history of landforms seems to suggest a more complex story. In fact, most of the direct effects of glacial impact are confined to the NE slope of the ridge, and they are mainly related to the areas interested by till deposition and glacial - related erosive phenomena, which seem to have cancelled all earlier soils. In the other areas, unaffected by glacier dynamics, obliteration of the past landcover is probably the result of the combination of two different factors: the strong periglacial processes and the nature of the parent material. In fact, being the lithology so easy to be weathered and eroded, large portions of the study area have simply been stripped bare to the bedrock, leaving great quantities of sediments deposited downslope at lower elevations. Regarding these deposits, only the glacis cover on the northern slope of Mt Bagioletto has been preserved; this is probably due to the relative stability of this area until recent time. On the contrary, deposits from the southern slope of Mt Cusna ridge might have been transported far below firstly by the Ozola glacier (during the glacial period), and then by stream dynamics. By the end of the Tardiglacial period the very dynamic environmental context left the study area in a virtually barren state, especially where claystones outcrop.

In this context the Holocene pedogenesis develops. The main pedogenic processes identified in the area allowed the formation mainly of Regosols and Cambisols (FAO, 2014), and, in some cases, Luvisols (FAO, 2014). Some general processes can be recognised, both active and inactive. The first is the progressive acidification of the soil profiles, which is clear from pH measurements for all studied profiles, but also from the analyses from exchangeable cations of the profiles on the paleosurface. Results from these analyses seem to indicate strong leaching processes which depleted in time the soil from most of its cation content. This is also evident by the role of carbonates in pedogenesis. Despite the presence of marlstones and limestones outcrops (marlstones and limestones levels are often associated to claystones and found as single stones or boulders on the present day surface), soils are completely free of carbonates. Tentative carbonate measurements were conducted both in the field and in the laboratory returning no results.

Water dynamics seem to have been influencing also the presence of clay. Clay illuviation is the second identified process and can be observed in many profiles both in the field and at the microscope. The presence of illuvial clay is typical in the buried units of the paleosurface profiles, but also in clayey soils at lower altitude (FG13/15, FG13/18) or even in soils formed on till deposits (F13/28). As seen from both optical microscope and SEM observations, clay coatings are composed by the finer clay fraction, which means mainly neoformed clay (i.e. mixed layer clays and illite; see chapter 5.7). These pedofeatures though, are widespread but rare in frequency: only a small amount of illuvial clay seems to be present compared to the total content of some of these soil profiles. This is probably related to the clay dynamics: when its content reaches values above 20% (Bullock and Thompson, 1985) or 30% (Soil Survey Staff, 2014) of total groundmass, clay is subject to shrink and swell movements, mixing the whole groundmass and obliterating or incorporating former coatings; the, pressure of the different peds swelling against each other forms over time clay reorientation hypocoatings (Kovda and Mermut, 2010, formerly defined stress argillans: Nettleton and Sleeman, 1985; see chapter 6.1). This phenomenon is enhanced by the parent material effect (e.g. Kooijman et al., 2005), which provides significant amounts of inherited clays to the soil groundmass. As a result, not only coatings disappear, but usually water circulation is impaired, giving way to the formation of redoximorphic features in deeper horizons in the form of mottles (Lindbo et al., 2010). Soils sharing these features are subjected to water saturation periodically: this can happen during snowmelt, but these soils can also retain water saturation conditions for days after periods of around a week of continuous rain. The illuviation process was probably more intense in the past. As seen in profile FG13/15, clay illuviation features are currently relict and no more in equilibrium with the present day pedoclimatic conditions, under which illuviation is no more an active process (Kühn et al., 2010).

7.2 - Weathering rates

The results of mineralogical analysis carried out on paleosurface profiles show that clay neoformation is not a strongly active process: the major fraction of the clay of the soil has been inherited from the parent material, as above discussed. In fact, the bedrock formations in the study area mainly contain clay minerals in the form of chlorite (Costa et al., 1992; Andreozzi and Di Giulio, 1994), which is consistent with the results of XRD analyses on parent material samples. In the analysed soil horizons, chlorites are still present together with the appearance of illite, probably from the weathering of muscovite and of mixed layer clays, which involve smectite formation usually from feldspars (Velde, 1995; Meunier, 2005). The presence of these weathering products seems to point to a general weakness of the pedogenesis, which can be compatible with soil formation in temperate or colder climates (Velde and Meunier, 2008). This is also in line with the hypothesis of a pedogenesis taking place the Holocene, especially for the absence of kaolinite, which in Italy is usually linked to Pleistocene pedogenesis (Costantini and Damiani, 2004), though clay composition does not give direct information about the duration of weathering processes.

Moreover, the measurement of the various forms of extractable iron oxides allow, through the calculation of opportune indices, to better characterise the nature and time frame of weathering occurring in these soils (see chapter 5.4). Comparisons with other data from soils chronosequences belonging to neighbouring areas in the Northern Apennines (Arduino et al., 1984; Arduino et al., 1986; Eppes et al., 2008) allow to see how the iron oxide segregation during weathering is consistent with the soil genesis confined in the Holocene: in fact, the crystalline/total iron ratio in particular is systematically lower than values found on soils dated to the Pleistocene. The values for free/total iron ratio in the same studies could suggest instead an earlier onset for pedogenesis. Nonetheless, deriving time frame considerations from free/total iron ratio alone could be misleading, since this index is more influenced by other pedogenetic factors than time (Cornell and Schwertmann, 2003). Free/total iron and amorphous/free iron ratios are in fact more useful to understand the nature of the weathering process. In general iron oxides are quite common in the soil, and at least a third of the total iron is in its free form. This is expected compared to the widespread presence of redoximorphic features as Fe-Mn nodules in all thin sections. Accordingly, free iron is mainly in its amorphous form, which can also points to a relatively young pedogenesis (Eppes et al., 2008).

Some other considerations may be done over particular processes. The 2Ab horizon from the paleosurface profiles is notable for its high free iron content, which amounts up to 60% of total iron. These results can be compared with the same values in other soils in the area (F14/02, F14/13 or FG14/19) which share instead a different genesis: in fact, their high iron content, especially in its amorphous form, is related to the general action of a Podzolization process (Duchaufour, 1977; 1983). This seems to have at least weakly happened also on the 2Ab horizon itself in its cryptopodzolisation form: clues can be found not only in the high free iron content of this horizon, but also on the values of the horizon below, usually strongly enriched in amorphous iron, as expected by theory (Duchaufour, 1983; Cornell and Schwertmann, 2003).

Considering again the paleosurface, many of the colluvial horizons show very low quantities of free iron which are in general very homogeneous for the whole deposit despite the apparent horizon differentiation inside these units (e.g.: F13/13). This could point to a lesser expression of pedogenesis inside the colluvium than assumed by field aspect and to a different combination of processes acting on it, which will be treated in the next chapter.

7.3 - Soil classification

The main active process can be defined as Brunification (Duchaufour, 1977; 1983). Given that the brunification process usually requires the presence of a temperate forest as cover (Duchaufour, 1983), its presence can be positioned in time since the establishment of this type of vegetation, which took place in the Early Holocene after deglaciation (Vescovi et al., 2010). Brunification developed with different intensities in the study area. In most cases soil development forms moderately developed Cambisols. Differences in development in this case are related mainly to the nature of the parent material, topographic conditions and rhexistasy phases. On till and landslide deposits pedogenesis is usually deeper and better expressed; drainage is high and has a positive effect on weathering and transport of its products (as can be seen from clay illuviation in profile FG13/28; see chapter 4.5.4), which can be progressively leached further inside the deposits, deepening the soil (Cremaschi and Rodolfi, 1991). The very gradual passage to progressively less developed horizons with depth inside these soils seems to be a confirmation of this process. Soils are shallower and less developed on steeper slopes, especially at lower elevations. Here leaching has probably a removal effect downslope instead. Slope instability is also present with periodical soil erosion and mixing events during pedogenesis.

The influence of tree root activity (i.e. bioturbation) probably has enhanced leaching processes and soil deepening in areas forested at present time or in the past. In this sense, soils above 1900 m seem to have withstood a relatively different process: here clay illuviation is absent and soils seem generally much shallower and devoid of striking features, as for example profile FG14/32 and the buried units of profile FG14/29 which are placed in the southernmost part of the ridge. This may be due to climate conditions at higher elevations which could have prevented the formation of the same forest cover as in sites at lower altitude.

The most developed soils in the area belong to Luvisols (FAO, 2014) or Alfisols (Soil Survey Staff, 2014). These are present mainly as the buried units of the paleosurface, which usually show better expressed clay illuviation and are related to flatter topography and to claystones as parent material. This is not always true: exceptions come from higher positions, where sandstones and elevation prevent clay accumulation and illuviation and only less developed soils can be found. Soil classification of paleosols is hardly accurate (Krasilnikov and Calderón, 2006; Nettleton et al., 1998) according to the available soil nomenclature codes (e.g. Soil Survey Staff, 2014; FAO, 2014). In fact, most of the key soil attributes have a low probability of being preserved in paleosols without major modification or destruction (James et al., 1998). Furthermore, in many cases, the classification of paleosols is not useful in paleoclimatic studies, as most of the diagnostic criteria depend on the present-day climate. Notwithstanding that, in order to compare paleosol sequences with current soils, analogies were made between the described paleosols and soil categories defined by the current international nomenclature (FAO, 2014). In particular 6 sample profiles from the paleosurface could be attributed to FAO categories with better detail. The result is as follows:

F13/04: Colluvic Regosol on Cutanic Dystric Luvisol
F13/05: Colluvic Regosol on Cutanic Dystric Luvisol
F13/06: Colluvic Regosol on Cutanic Dystric Luvisol
F13/08: Colluvic Cambisol on Cutanic Dystric Luvisol
F13/10: Colluvic Eutric Cambisol on Cutanic Luvisol
F13/12: Colluvic Abruptic Cambisol on Cutanic Dystric Luvisol

It is interesting to consider that these soils, in particular the buried units, seem the more developed in the area, even considering the soils at lower elevations, which were subject to warmer conditions and continued their development under a continuous forest potentially for a long period of time after the truncation and successive burial of the paleosols. This seems paradoxical, but is only partly true. First, there is to consider the topographic context. These soils, especially F13/04, F13/05 and F13/06 (which are the most developed), are placed in a flat area on strongly weathered clays and with intermittent water saturation. In these conditions iron mobilisation and formation of clay illuviation features are highly enhanced. Most of the rest of the area is composed by more or less steep slopes, which favour drainage and leaching and generally tend to express weaker soil formation, as already noted above. In another position in which the same conditions are met profile FG13/15 and FG13/18 are formed, which present very mature features of pedogenesis and can be qualified as well developed Luvisols.

Moreover, thin sections from many soil profiles show a change in environmental conditions which slowed or even stopped clay illuviation (as said in chapter 6.4) in favour of shrink and swell movements, which in these two profiles are best expressed with the formation of slickensides (Soil Survey Staff, 1975; see chapter 6.4). The result of these movements is a mixing of the groundmass which has probably destructed many of the soil features present there. It is possible that many forest soils are still affected by this phenomenon, as buried units are probably isolated, and may have retained many of their older features. In this case, as pedogenesis of the paleosurface was interrupted by rhexistasy events, pedogenesis in lower areas was slowed down by the same climate changes that triggered them.

Chapter 8

Soil history on Mt Cusna ridge: pedogenesis through the Holocene

8.1 - Early-Middle Holocene

Formation of Luvisols is the result of climatic effects which took place in the past and essentially culminated during the Holocene Climatic Optimum (Compostella et al., 2012). In this period, environmental conditions were sensibly warmer and more favourable than present, allowing the formation of a temperate forest cover (confirmed by anthracological assemblages inside the paleosol: Cremaschi et al., 1984; Compostella et al., 2012) and the full expression of the pedogenetic processes illustrated before. Not much else is known for lack of available data. From thin sections it is possible though to detect changes which brought to the end of this phase and the beginning of a climatic recrudescence.

In fact, three successive illuviation phases have been recognised (see chapter 6.1), likely related to three different environmental stages. The first phase is represented by microlaminated clay coatings in the deepest part of profiles. Their presence is compatible with stable, continuous vegetation cover and a strong seasonality in climate (e.g. Fedoroff, 1997, described for Mediterranean soils). At similar depths or above this first phase is found a second phase of nonlaminated clay coatings, which is compatible with climatic conditions lacking strong seasonal contrasts, or is indicative of the final phase of clay illuviation (Kühn et al., 2010; Miedema et al., 1999; Rogaar et al., 1993). Illuviation of coarser fractions (dusty clay and silt coatings) indicates loss of stable vegetation cover and marks a final phase of soil erosion.

After that, no more evidence of translocation of fine material is present. On the contrary, there is ample evidence of a process of incorporation of these coatings into the soil, where sometimes a striated b-fabric remains as the only visible trace (see chapter 6.1, 6.4). This phenomenon suggests that coatings are no longer in equilibrium with the present conditions. All these features suggest the arrival of a recrudescence phase which caused a lowering of the treeline (Compostella et al., 2012) and the successive truncation and erosion of many soils without the protection of a stable forest cover.

8.2 - Late Holocene and the formation of the 2Ab horizon

Paleosol truncation marks the passage to a different climate period. A ^{14}C date from charcoals found inside a 3Bw horizon of the buried unit of the paleosurface gives the result of 3920-3700 cal yr BP (Compostella et al., 2012). A bulk soil sample of a buried horizon placed on the ridge crest near Mt Cusna was instead dated to 3562-3383 cal yr BP (Giraudi, 2014). Both dates point to the climatic recrudescence phase taking place during the Subboreal period. This is a phase of slope instability well known for all the Northern Apennines (Bertolini, 2007).

From this point soil development changes. Potential for Luvisols probably disappears from the area: as a consequence, many pedogenetic processes disappear or become sensibly weaker (especially at lower elevations). At the same time slope instability causes strong erosion and probably a period of landslide events forming many new deposits in the area. In many areas the bedrock is uncovered and pedogenesis starts again on new material: this could have possibly as possibly happened in the case of profile FG14/32 and in general on many slopes above and below the forest. This is also the probable start of the conditions for deposition of the colluvial layers, even though evidence suggests that many of them were in fact deposited in a later period. From this moment two main processes act in the area, not completely independent from each other.

The first process taking form is Podzolisation (Duchaufour, 1977; 1983). Despite the potentiality for Podzols (FAO, 2014), which probably starts form this period onwards, their presence in the area is very patchy and limited to heathland covered areas above the treeline, mainly on N facing slopes. The most developed Podzol found is F14/13, located outside the study area in the SW, on the NE-facing slope of the Ozola valley, just above the present treeline. This soil lacks some of the typical features of a Podzol, in particular a real E horizon, which is not fully formed and shows the characteristics of a AE horizon. Since the E horizon is the last to form in the Podzolisation sequence, during a deepening process which could take hundreds to thousands of years to fully develop (Buurman and Jongmans, 2005), the start of this pedogenesis can be dated to after the Subboreal instability.

In the rest of the area the development of Podzolisation features is quite weak, and it probably forms less differentiated soils (*ranker criptopodzolique*: Duchaufour, 1983), as it can be seen in profiles F14/02 and FG14/46. The former is placed on a location similar to F14/13 (uniform slope facing NE, heathland cover), though about 200 m higher. FG14/46 is instead placed on the southern slope of the ridge, and is related to the presence of water saturation caused by marlstones: in this case the profile probably shows some characteristics of an Hydromorphic Podzol (Duchaufour, 1983). In general, though, pedogenesis still tends to the development of Cambisols. The causes for this phenomenon are difficult to assess. It could be either related to soil acidity being insufficient for iron complexation by organic acids to happen, or the effect of unfavourable climatic forcing. In any case, Podzolisation in the area can be considered a secondary process.

The second process taking place after the Subboreal recrudescence is the formation of the 2Ab horizon, present in many soils of the paleosurface as a distinct layer lying above the main buried unit. Many features mark it as a different unit than both the underlying paleosol and the overlying colluvium. From laboratory analyses can be seen how grain size distribution shows a stronger prevalence of fine components through a consistent decrease in coarse material; another interesting aspect is the presence of large amounts of organic carbon in this horizon, sometimes even more than the present soil surface. Both these features point to a phase of accumulation of organic and fine material in the form of silt-size granules composing the main part of the fabric. These at the microscope show a regularity in shape and dimensions that can identify them as excrements from an especially abundant invertebrate activity. A similar micromorphological pattern has been found in buried organic horizons also in Central Europe, and linked to the same phenomenon (M. Kooistra, personal communication). Studies on insect remains found inside this horizon can likely associate these excrements to the presence of Curculionidae, Aphodidae and Chrysomelidae (Coleoptera) and Formicidae (Hymenoptera), which are all epigean taxa (Compostella et al., 2012). This accumulation of fine excrements full in organic matter has been well conserved inside the soils without reworking. This can be related to cold mountain climate conditions which reduce mineralisation rate and slow pedoplasmation (Stoops and Schaefer, 2010), as is found in mor and tangel humus forms (Zanella et al., 2011).

As discussed before, inside this horizon cryptopodzolisation features can be found (see chapter 7.2), essentially related to a high presence of amorphous iron partially leaching into the horizon below. The origin of free iron oxides is probably again due to the effect of redoximorphic conditions, as can be seen by the presence of Fe-Mn nodules visible in thin sections inside the groundmass. Together with nodules, charcoal fragments are found, both macroscopic and microscopic. The anthracological assemblage found inside this horizon in profile F13/04 shows the presence of Laburnum sp., Abies alba, and Vaccinium sp. (Compostella et al., 2012), which indicate the presence of a loosely forested heathland. This can confirm both the passage to colder conditions from a full forest cover and the development of Podzolisation features, which can be helped by the presence of heathland (*callune* in Duchaufour, 1977; 1983).

From these features, it can then be concluded that the 2Ab horizon is the result of the accumulation of organic material and fine excrements from invertebrate activity, whose decomposition and pedoplasmation were strongly limited by colder climate conditions. On this new surface can be found evidence of the action of both redoximorphic conditions and weakly developed podzolisation. The vegetation on this surface was mainly composed by a forested heathland which was probably removed by fire events which produces relevant amounts of charcoals which are still conserved inside this soils. A ^{14}C date from insect remains inside the 2Ab horizon of profile F13/04 gives a result of 640-590 and 570-530 cal yr BP. A charcoal fragment from profile F13/10 gives a date of 790-670 cal yr BP (Compostella et al., 2012). Thus the removal of the forested heathland can be placed inside the

Late Medieval period, which historical sources link to the return of human stable settlements in the valleys below (Panizza et al., 1982).

8.3 - The Little Ice Age and colluvial deposition

Other features present in the 2Ab horizon provide information on its final burial by colluvial deposits. The void patterns of parallel-perpendicular planes, wedges, and secondary prismatic structure are all related to frost action, in particular to the formation of an isoband fabric (Dumanski and St-Arnaud, 1966) formed by ice segregation lenses and consequent desiccation of the soil mass (Van Vliet-Lanoë, 1998). This process has acted mainly on the soil surface, as it can be deduced by the presence of clayey pedorelicts inside one of the vertical wedges in profile F13/04, which have probably fallen inside. These pedorelicts also show that frost conditions were active at the time of the burial of this unit. This allows to date the period of colluvial deposition more precisely. In fact, frost features are the last process acting on these horizons, as they are often superimposed to all the other soil components, including Fe-Mn nodules and charcoals. Since charcoals from this horizon were produced during the Late Medieval ages, the only colder period after it in which these features could have been formed is the Little Ice Age (LIA). This phase of climatic recrudescence has probably had an impact on slope stability, triggering colluvial events in the area which dismantled or buried the older soils in different locations. In fact, preservation of the 2Ab horizons only in flat areas may be a result of its removal from the steeper slopes, where in cases only the paleosol below was preserved under the colluvium.

Understanding the formation of colluvial deposits is quite important to reveal the recent landscape evolution. The main feature many of these colluvial deposits have in common is the presence of an apparently developed soil formation. In the field, this unit has a very uniform appearance, being weakly structured and with significant quantities of coarse rock fragments. The latter decrease with depth, in 'more developed' AB horizons having an increase of chroma and more clayey textures. These characteristics seem to indicate the nature of this unit as an event of colluvium, which was influenced after its deposition by in situ pedogenesis, apparently the same in the whole area. This unit is similar in appearance to 'cover-beds' (Kleber, 1997), even if the latter are more strictly defined as slope deposit related to periglacial dynamics, as described in Austria and Germany (Semmel and Terhorst, 2010; Terhorst, 2007).

In thin section, however, all horizons, including the 'more developed' AB ones, show the characteristics of a mass-transported soil (Fedoroff et al., 2010) with only very weak signs of pedogenesis acting after deposition. Colour of micromass in thin sections, degree of porosity, and b-fabric indicate very weak pedogenetic development. Star-shaped vughs in AB horizons are not diagnostic since they can be attributed both to mechanical compaction and pedogenesis (Aurousseau et al., 1985; Fedoroff et al., 2010). On the contrary, the groundmass appears to be composed of a high proportion of subrounded to subangular pedorelicts. Their internal fabric is comparable with the underlying 2Bw horizons: this can indicate their origin from dismantled soils similar to those found in the buried unit. Consequently, the presence of pre-altered material (Stoops, 1989) inherited from the slope could explain the apparent development of some horizons at the field observation level. In this light, present-day pedogenesis on the upper unit appears less effective than thought, because of its weakness or its short time of action, possibly both.

The origin of this apparent pedogenesis could have possibly been helped by the erosive processes causing colluvial deposition. A progressive removal of soil material from higher topographic positions could have formed colluvial units downslope with the inferior part richer in dismantled soil material. Successive colluvial episodes could have been progressively enriched in rock fragments as soils got replaced by bare outcrops. Another characteristic is the presence of multiple colluvial events, visible in thin section in profiles F13/12 and F13/13, but also in profile FG14/36 (see chapter 6.3). In these cases the colluvial units may have been formed by the effect of continuous smaller phases of progressive erosion similar to those described above or by a fewer number of deposition events well separated in time.

Aside from the presence of pedorelicts and sometimes oriented clasts, colluvial deposits fail to show other relevant features, and in many cases have the aspect of very uniform layers of randomly organized material. This could be again related to frost action in the form of cryoturbation, which tends in its first phases to favour mixing of the soil material (Van Vliet-Lanoë, 1998) with the result of a general homogenisation inside colluvial horizons; the absence of clear frost features in thin sections from these horizons is possibly due to this process.

The absence of stronger frost features related to solifluction inside these colluvial units can have implications from a climatic point of view. In fact solifluction today is present at these elevation only as relict lobe-shaped areas on the N slope of Mt. Bagioletto and in many other places. The only signs of presently active processes are limited to the areas where snow cover is insufficient to protect soils from winter frost, which are mainly located on steep slopes at higher elevations. Nevertheless, solifluction must have been active and widespread during the LIA, as the presence of relict lobes and of frost features on the 2Ab horizon seem to imply. This can be easily explained by the presence of a colder climate, but another reason may also be involved. In fact, potential for solifluction should still be present in the area even at lower elevations, considering mean winter temperatures (see chapter 2.5). This does not happen because of the presence from november to april of a layer of snow at least 50 cm thick at 1500 m (Panizza et al.,1982), which effectively isolates the soil below from frost events (Edwards et al., 2007 and references therein).

This could imply the presence during the LIA of drier conditions, with reduced autumn and winter snow precipitations, which would have strongly impaired the formation of frost under the soil surface and the development of solifluction features.

Chapter 9

Conclusions

This study outlined the existence of complex interactions between pedogenic, geomorphic and environmental processes throughout the Holocene. The influence of these aspects on soil features could be detected and used to describe and interpret the present landscape in the light of its modifications through time.

The production of a large scale geomorphological map had a relevant importance in framing the main active and inactive processes shaping the area and permitted to reconstruct how these interacted through time. Traces from glacial and periglacial processes allowed to estimate the landscape conditions at the end of the last glaciation. Moreover, during the Holocene, different phases of stability and instability have been detected from the activation of slope dynamics as the result of both climate variations and structural constraints, with a relative prevalence of erosion or deposition according to the intensity of surface processes.

In this context soil diversity could be assessed and attributed to multiple landscape units, highlighting differences in process and development between them. In particular, it was possible to recognise how the different parent materials (whether claystones, sandstones or till and other deposits) and topographic conditions (elevation, slope inclination and exposition among others) constituted the main elements in order to categorise soil formation. The conditions for the formation of the paleosurface were also assessed and related to different phases of bio/rhexistasy.

The analytic approach to the characterisation of the soils in the area was successful in providing a larger view of the pedogenetic processes acting on the various surfaces. This was obtained through a careful choice in soil sampling on order to investigate the maximum diversity in soil composition. The application of general analyses on a wider range of soils was carried out in parallel with the investigation of peculiar situations with more advanced and precise laboratory techniques: the main result was a diversified range of data which could be used to both describe general processes and identify variations between different soils and areas.

Through these findings, the value of micromorphological analysis within this context becomes evident. An important contribution comes from its higher level of resolution in outlining different phases of soil development compared with field and laboratory observation only. In this way, it provides a fundamental role in designing a framework where extremely various data from different analyses can be placed. Micromorphology also allows the extrapolation to wider areas of data available only for single sites, such as charcoal assemblages or features of frost action.

As a result of these approaches, it was possible to identify the main and minor processes involved in soil formation in the area, also considering local situations. The presence of different phases of pedogenesis during the Holocene could be assessed, as well as the prevalence of the various pedogenetic and geomorphic processes in each phase. Weathering rates from clays and iron oxides could also give some information about duration and strength of pedogenesis. Extensive analyses also permitted a classification of the soils according to the standard soil systems.

These considerations could be used to reconstruct the history of pedogenesis in a better detail, outlining the main variations in the action of processes and the influence of factors through the various phases of the Holocene. In particular, key periods in the formation of these soils were highlighted and better characterised for their importance on the evolution of both soils and landscape. In the end, these findings also provided new interpretations to integrate inside the current reconstructions of recent environmental change both for the area and at a wider scale.

Chapter 10

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Chapter 11

Appendices

11.1 - Appendix 1 - Soil field descriptions

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
F13/01	A1	0-6	10 YR 2/2	Moist	Loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine	abundant	Very fine to fine	Common	Clear	Smooth	
	A2	6-12	7,5 YR 3/3	Moist	Clay loam	Sub. blocky	Fine	Weak	Absent	Absent	Absent	Absent	Fine	Common	Fine	Common	Clear	Smooth	
	Bw	12-33	10 YR 3/6	Moist	Sandy clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Few	Very fine	Few	Medium	Few	Gradual	Smooth	
	BC	33-40+	10 YR 3/6	Moist	Sandy clay loam	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Frequent	Very fine	Few	Fine	Few	Absent	Absent	
F13/02	A1	0-16	10 YR 4/4	Moist	Loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine to medium	abundant	Very fine to fine	Abundant	Clear	Smooth	
	A2	16-26	10 YR 4/4	Moist	Sandy clay loam	Granular	Fine	Moderate	Sandstone	Gravel	Subang.	Very few	Fine	Few	Very fine to fine	Common	Clear	Smooth	
	CB	26-40+	10 YR 3/6	Moist	Clay loam	Sub. blocky	Fine	Weak	Sandstone	Gravel and stones	Subang. /Flat	Few to Frequent	Fine	Very few	Very fine	Frequent	Absent	Absent	
F13/03	O	0-2	7,5 YR 4/2	Dry	Clay loam	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Very fine to fine	Few	Fine	Few	Clear	Smooth	
	A1	2-30	7.5 YR 5/2	Dry	Silt clay loam	Granular	Fine	Weak	Claystone	Gravel	Ang.	Common	Absent	None	Very fine to fine	Few	Clear	Smooth	
	A2	30-50	10 YR 4/3	Dry	Silty clay	Ang. blocky	Fine	Weak	Claystone	Gravel	Ang.	Frequent	Absent	None	Very fine to fine	Very few	Clear	Smooth	
	2Ab	50-60	10 YR 3/3	Moist	Clay	Ang. blocky	Fine	Weak	Claystone	Gravel	Flat	Few	Absent	None	Absent	None	Clear	Smooth	
	3Bw	60-70	10 YR 4/4	Moist	Clay	Ang. blocky	Fine	Weak	Claystone	Gravel	Ang.	Common	Absent	None	Absent	None	Clear	Smooth	
	3Bt	70-95	10 YR 3/6	Moist	Clay	Ang. blocky	Medium	Moderate	Claystone	Gravel	Subang.	Very few	Absent	None	Absent	None	Gradual	Smooth	Clay coatings
	3BC	95-120+	7.5 YR 3/2	Moist	Clay	Ang. blocky	Medium	Moderate	Claystone	Gravel	Flat	Very few	Fine	Frequent	Very fine	Few	Absent	Absent	
F13/04	A1	0-15	7.5 YR 4/3	Dry	Clay loam	Granular	Medium	Moderate	Claystone	Gravel	Flat	Frequent	Absent	None	Very fine to fine	Very few	Clear	Smooth	
	A2	15-36	10 YR 3/4	Dry	Silty clay	Granular	Fine	Moderate	Claystone	Gravel	Flat	Frequent	Absent	None	Very fine to fine	Very few	Clear	Smooth	
	AB	36-50	7.5 YR 4/4	Moist	Clay loam	Sub. blocky	Fine	Weak	Claystone	Gravel	Subang.	Few	Absent	None	Fine	Very few	Clear	Smooth	
	B	50-70	10 YR 2/2	Moist	Clay	Sub. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Very few	Absent	None	Fine	Very few	Abrupt	Smooth	Clay coatings
	2Ab	70-75	7.5 YR 4/6	Moist	Silt loam	Sub. blocky	Fine	Strong	Absent	Absent	Absent	Absent	Very fine to fine	Few	Fine	Frequent	Gradual	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	3Bt	75-90	10 YR 4/4	Moist	Silty clay	Sub. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Very few	Absent	None	Very fine to fine	Very few	Gradual	Smooth	
	3BC	90-100+		Moist	Silty clay	Ang. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Frequent	Very fine to fine	Very few	Very fine	Very few	Absent	Absent	
F13/05	A1	0-15	7.5 YR 3/2	Dry	Silt clay loam	Granular	Coarse	Moderate		Gravel	Flat	Few	Fine	Few	Medium	Few	Clear	Smooth	
	A2	15-25	7.5 YR 2.5/2	Dry	Silty clay	Granular	Medium	Moderate		Gravel	Flat	Very few	Very fine to fine	Very few	Fine	Common	Clear	Smooth	
	2Ab	25-30	7.5 YR 3/3	Dry	Silt clay loam	Granular	Medium	Weak	Absent	Absent	Absent	Absent	Absent	None	Very fine to fine	Very few	Clear	Smooth	
	3Bw	30-40	10 YR 3/4	Dry	Silt clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Subang.	Very few	Very fine to fine	Very few	Medium	Few	Abrupt	Smooth	
	3Bt	40-65	10 YR 4/3	Moist	Clay loam	Ang. blocky	Medium	Moderate	Claystone	Gravel	Flat	Very few	Very fine	Very few	Very fine to fine	Very few	Clear	Smooth	
	3BC	65-80+	10 YR 5/4	Moist	Silt clay loam	Ang. blocky	Coarse	Moderate	Claystone	Gravel	Subang.	Few	Very fine	Few	Very fine	Very few	Absent	Absent	
F13/06	O	0-5	7,5 YR 4/2	Dry	Clay loam	Absent	Absent	Absent					Very fine to fine	Few	Fine	Frequent	Abrupt	Smooth	
	A1	5-20	7.5 YR 4/3	Dry	Loam	Granular	Fine	Weak					Very fine	Very few	Very fine to fine	Very few	Clear	Smooth	
	A2	20-37	7.5 YR 5/3	Dry	Loam	Granular	Fine	Moderate					Absent	None	Very fine	Very few	Clear	Smooth	
	AB	37-47	7.5 YR 4/4	Moist	Loam	Sub. blocky	Fine	Moderate					Absent	None	Very fine	Very few	Abrupt	Wavy	
	2Ab	47-54	7.5 YR 2/3	Moist	Silt clay loam	Sub. blocky	Very fine	Moderate	Absent	Absent	Absent	Absent	Very fine	Very few	Fine	Few	Clear	Smooth	
	3Bt	54-80	7.5 YR 4/4	Moist	Clay loam	Ang. blocky	Fine	Moderate					Absent	None	Very fine	Very few	Clear	Smooth	
	3CBg	80-95+	7.5 YR 3/3	Moist	Sandy loam	Ang. blocky	Fine	Moderate					Very fine	Very few	Absent	None	Absent	Absent	
F13/07	O	0-5	7.5 YR 2.5/3	Moist	Clay loam	Granular	Fine	Moderate	Absent	Absent	Absent	Absent	Very fine to fine	Abundant	Very fine to fine	Abundant	Clear	Smooth	
	A	5-14	7.5 YR 2.5/2	Moist	Sandy clay loam	Granular	Fine	Moderate	Absent	Absent	Absent	Absent	Very fine	Common	Very fine	Common	Clear	Smooth	
	E	14-24	10 YR 4/4	Moist	Clay loam	Granular	Medium	Weak	Absent	Absent	Absent	Absent	Fine	Few	Very fine	Common	Clear	Smooth	
	B	24-45	10 YR 3/4	Moist	Clay loam	Granular	Medium	Strong	Claystone	Gravel	Subang.	Few	Fine	Very few	Very fine	Few	Clear	Smooth	
	BC	45-56	10 YR 4/4	Moist	Clay loam	Sub. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Few	Absent	None	Very fine	Few	Clear	Smooth	
	CB	56-80+	10 YR 4/3	Moist	Clay	Sub. blocky	Medium	Moderate	Claystone	Gravel	Subang.	Common	Absent	None	Absent	None	Absent	Absent	
F13/08	A1	0-4	7,5 YR 4/2	Moist	Loam	Granular	Fine	incoerente	Sandstone	Gravel	Subang.	Very few	Medium	Abundant	Very fine	Common	Abrupt	Smooth	
	A2	4-22	7,5 YR 4/2	Moist	Silty clay	Granular	Fine	incoerente	Sandstone	Gravel	Subang.	Common	Medium	Abundant	Very fine	Frequent	Abrupt	Smooth	
	AB	22-44	2.5 Y 4/4	Moist	Clay	Sub. blocky		Weak	Sandstone	Gravel	Subang.	Few	Fine	Common	Very fine	Frequent	Clear	Broken	
	2Bt	44-68	7,5 YR 4/6	Moist	Clay	Ang. blocky		Moderate	Sandstone	Gravel	Subang.	Frequent	Very fine	Few	Very fine	Few	Abrupt	Broken	
	2BCg	68-80+	7,5 YR 4/4	Moist	Clay	Ang. blocky		Weak	Sandstone	Gravel and stones	Ang.	Common	Very fine	Few	Very fine	Very few	Absent	Absent	
F13/09	A	0-6	2.5 Y 6/2	Dry	Silt loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Very fine to fine	Frequent	Medium	Frequent	Abrupt	Smooth	
	AB1	6-12	2.5 Y 6/3	Moist	Silt loam	Granular	Medium	Weak	Claystone	Gravel	Flat	Few	Very fine	Very few	Medium	Frequent	Abrupt	Smooth	
	AB2	12-34	2.5 Y 6/4	Moist	Loam	Sub. blocky	Medium	Weak	Sandstone / Claystone	Gravel	Subang. /Flat	Frequent	Absent	None	Fine	Frequent	Abrupt	Smooth	
	B	34-44	2.5 Y 6/4	Moist	Clay loam	Sub. blocky	Coarse	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Few	Absent	None	Fine	Few	Clear	Broken	
	2Bw1	44-60	10 YR 5/6	Moist	Clay	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Very fine	Few	Medium	Frequent	Clear	Irregular	
	2Bw2	60-70	10 YR 4/6	Moist	Clay loam	Sub. blocky	Coarse	Strong	Claystone	Gravel	Flat	Frequent	Absent	None	Coarse	Few	Abrupt	Smooth	
	2BCt	70-100+	10 YR 4/6	Moist	Sandy loam	Sub. blocky	Coarse	Moderate	Claystone	Gravel	Flat	Common	Absent	None	Absent	None	Absent	Absent	
F13/10	O	0-3	10 YR 5/2	Dry	Sand	Granular	Fine	Weak	Claystone	Gravel	Flat	Few	Medium	Frequent	Fine	Frequent	Abrupt	Smooth	
	A1	3-20	2.5 Y 7/2	Dry	Sandy loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Medium	Frequent	Fine to medium	Frequent	Clear	Smooth	
	A2	20-28	10 YR 7/2	Moist	Sandy loam	Sub. blocky	Fine	Weak	Claystone	Gravel	Flat	Very few	Medium	Frequent	Fine	Frequent	Abrupt	Smooth	
	AB	28-36	10 YR 6/2	Moist	Clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Few	Fine	Few	Very fine	Very few	Clear	Smooth	
	2Bw	36-43	10 YR 7/4	Moist	Clay	Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Fine	Very few	Very fine	Very few	Clear	Smooth	
	3Bt	43-60	10 YR 6/4	Moist	Clay	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Fine	Very few	Very fine	Very few	Clear	Wavy	
	3Btg	60-105	10 YR 6/3	Moist	Clay loam	Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Very fine	Very few	Very fine	Very few	Abrupt	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	3BtC	105-130	10 YR 7/3	Moist	Sandy loam	Sub. blocky	Fine	Weak	Claystone	Gravel	Flat	Few	Very fine	Very few	Absent	None	Absent	Absent	
F13/11	O	0-5															Abrupt	Smooth	
	A	5-50	7.5 YR 2.5/2	Dry	Loam	Granular	Fine	Weak									Diffuse	Smooth	
	AB	50-110	10 YR 3/2	Moist	Clay loam	Granular	Fine	Moderate									Clear	Smooth	
	2Bt1	110-140	10 YR 3/4	Moist	Silty clay	Sub. blocky	Fine	Moderate									Abrupt	Wavy	
	2Bt2	140-150	7.5 YR 3/4	Moist	Silty clay	Sub. blocky	Fine	Strong									Abrupt	Wavy	
	2Bt3	150-180	7.5 YR 4/4	Moist	Silty clay	Sub. blocky	Fine	Strong									Clear	Wavy	
	2BC	180-200 +	10 YR 4/3	Moist	Silt clay loam	Sub. blocky	Fine	Moderate									Absent	Absent	
F13/12	A1	0-8	10 YR 4/2	Moist	Clay loam	Granular	Fine	incoerente	Absent	Absent	Absent	Absent	Fine	abundant	Fine	Dominant	Abrupt	Smooth	
	A2	8-22	10 YR 5/2	Moist	Sandy clay loam	Granular/ Sub. blocky	Fine	Weak	Claystone	Gravel	Subang.	Few	Fine	abundant	Fine	Common	Clear	Smooth	
	AB	22-43	2.5 Y 4/4	Moist	Silt clay loam	Sub. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Few	Fine	Abundant	Fine	Common	Clear	Smooth	
	2Bw1	43-71	2.5 Y 4/4	Moist	Silt loam	Sub. blocky	Fine	Moderate	Claystone	Gravel	Subang.	Frequent	Fine	Few	Very fine	Few	Clear	Wavy	
	2Bw2	71-83	2.5 Y 4/4	Moist	Clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Subang.	Few	Fine	Very few	Very fine to fine	Very few	Clear	Smooth	
	3Bt1	83-100	10 YR 5/3	Moist	Clay	Sub. blocky	Medium	Strong	Claystone	Gravel	Subang.	Very few	Absent	None	Absent	None	Clear	Smooth	Clay coatings
	3Bt2	100-120 +	10 YR 5/4	Moist	Clay	Sub. blocky	Medium	Strong	Absent	Absent	Absent	Absent	Absent	None	Absent	None	Absent	Absent	Clay coatings
F13/13	O	0-5															Clear	Smooth	
	A	5-33	2.5 Y 4/2	Dry		Granular	Fine	Weak					Fine	Abundant	Fine	Frequent	Clear	Smooth	
	BA	33-50	2.5 Y 4/4	Moist		Sub. blocky	Fine	Moderate					Fine	Frequent	Very fine	Few	Clear	Smooth	
	2Bw1	50-70	2.5 Y 4/4	Moist		Sub. blocky	Medium	Moderate					Very fine to fine	Frequent	Very fine	Very few	Gradual	Smooth	
	2Bw2	70-100	2.5 Y 4/4	Moist		Sub. blocky	Medium	Strong					Very fine to fine	Very few	Absent	None	Clear	Smooth	
	3Bw	100-120	10 YR 4/4	Moist		Sub. blocky	Coarse	Strong					Absent	None	Medium	Very few	Clear	Smooth	
	3Bt	120-130 +	10 YR 4/6	Moist		Ang. blocky	Medium	Strong					Absent	None	Absent	None	Absent	Absent	Clay coatings
FG13/14	A	0-5	10 YR 3/3	Dry	Silt loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Fine	Common	Very fine to fine	Common	Abrupt	Smooth	
	AB	5-12	10 YR 4/4	Dry	Silty clay	Granular	Fine	Moderate	Claystone	Gravel	Flat	Very few	Very fine	Common	Very fine to fine	Common	Clear	Smooth	
	BA	12-30	10 YR 3/6	Dry	Loam	Granular	Medium	Strong	Claystone	Gravel	Flat	Very few	Fine	Abundant	Fine	Common	Gradual	Smooth	
	BC	30-50	10 YR 4/4	Moist	Sandy clay	Granular/ Sub. blocky	Fine	Strong	Claystone	Gravel	Flat	Frequent	Fine	Frequent	Very fine	Frequent	Abrupt	Smooth	
	2BC	50-75	2.5 Y 4/4	Moist	Clay loam	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Common	Fine	Very few	Very fine	Few	Clear	Wavy	Mottles 2.5 Y 3/2
	2C	75-90+	2.5 Y 3/2	Moist	Clay	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Common	Absent	None	Absent	None	Absent	Absent	
FG13/15	A	0-20	2.5 Y 5/2	Moist		Granular	Fine	Weak	Claystone	Gravel	Flat	Few	Very fine	Abundant	Very fine to fine	Common	Clear	Smooth	
	EB	20-50	2.5 Y 5/2	Moist		Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Frequent	Very fine	Common	Very fine	Frequent	Clear	Smooth	
	Bt	50-70	2.5 Y 4/4	Moist		Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Few	Very fine	Few	Very fine	Few	Clear	Smooth	Clay coatings
	BtCg	70-90+	2.5 Y 4/4	Moist		Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Abundant	Absent	None	Fine	Few	Absent	Absent	Clay coatings
FG13/16	O	0-10	2.5 Y 4/2	Dry	Clay loam	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Very fine to fine	Frequent	Very fine to fine	Abundant	Abrupt	Smooth	
	A	10-70	2.5 Y 4/4	Moist	Silt clay loam	Granular	Fine	Moderate	Claystone	Gravel	Flat	Frequent	Very fine	Very few	Very fine	Common	Clear	Smooth	
	AC	70-100	2.5 Y 4/4	Moist	Silt clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Common	Absent	None	Absent	None	Clear	Smooth	
	2Bt	100-140	10 YR 4/4	Moist	Silty clay	Sub. blocky	Medium	Strong	Sandstone / Claystone	Gravel	Subang. /Flat	Common	Absent	None	Absent	None	Clear	Smooth	Clay coatings
	2BC	140-200 +	10 YR 4/3	Moist	Silt loam	Sub. blocky	Fine	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Common	Absent	None	Absent	None	Absent	Absent	Clay coatings
FG13/17	O	0-6	2.5 Y 4/2	Dry	Clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Very fine to fine	Common	Medium	Abundant	Abrupt	Smooth	
	A	6-14	2.5 Y 4/4	Dry	Loam	Granular	Medium	Moderate	Absent	Absent	Absent	Absent	Very fine to fine	Frequent	Fine	Common	Clear	Wavy	
	Bw	14-40	10 YR 5/4	Moist	Silt loam	Sub. blocky	Fine	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Few	Very fine to fine	Few	Fine	Few	Clear	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	2Bw	40-55	10 YR 4/6	Moist	Silty clay	Sub. blocky	Fine	Moderate	Claystone	Gravel	Flat	Few	Very fine	Very few	Fine	Few	Clear	Wavy	
	2Bg	55-65	2.5 Y 4/4	Moist	Silty clay	Sub. blocky	Fine	Moderate	Claystone	Gravel	Flat	Frequent	Very fine	Very few	Medium	Frequent	Clear	Smooth	
	2BC	65-100+	2.5 Y 4/4	Moist	Clay	Sub. blocky	Coarse	Strong	Claystone	Gravel	Flat	Frequent	Absent	None	Very fine to fine	Few	Absent	Absent	
FG13/18	O	0-4	7.5 YR 3/2	Dry	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine	Abundant	Fine	Abundant	Abrupt	Smooth	
	A	4-23	10 YR 4/4	Dry	Silt clay loam	Ang. blocky	Medium	Moderate					Very fine	Few	Fine	Common	Abrupt	Smooth	Mottles
	Bt1	23-34	10 YR 4/3	Moist	Sandy loam	Sub. blocky	Fine	Moderate					Very fine	Few	Very fine to fine	Common	Clear	Wavy	
	Bt2	34-67	2.5 Y 4/2	Moist	Silty clay	Ang. blocky	Medium	Moderate					Very fine to fine	Very few	Very fine	Few	Clear	Wavy	Fe-Mn circular coatings, clay coatings, mottles
	BtCg	67-90+	10 YR 4/3	Moist	Silty clay	Ang. blocky	Fine	Strong					Absent	None	Absent	None	Absent	Absent	Fe-Mn nodules, clay coatings, mottles
FG13/19	E	0-6	10 YR 5/4	Dry	Sandy loam	Granular	Fine	Weak	Sandstone / Claystone	Gravel	Subang.	Few to common	Fine	Frequent	Very fine to fine	Common	Clear	Smooth	
	Bw	6-35+	10 YR 4/6	Dry	Silt clay loam	Granular	Fine	Weak	Sandstone / Claystone	Gravel	Subang.	Few to common	Fine	Frequent	Very fine to fine	Common	Absent	Absent	
FG13/20	A	0-10	2.5 Y 4/4	Dry	Sandy clay loam	Granular	Fine	Weak	Sandstone / Claystone	Gravel and stones	Subang.	Frequent	Fine	abundant	Very fine to fine	Common	Clear	Smooth	
	E	10-45	10 YR 5/3	Dry	Sandy loam	Granular	Fine	Very weak	Sandstone / Claystone	Gravel and stones	Subang.	Few	Fine	Common	Very fine	Frequent	Clear	Smooth	
	C	45-60+	10 YR 5/3	Moist	Sandy clay loam	Absent	Absent	Absent	Sandstone	Stones and boulders	Ang.	Abundant	Medium	Common	Very fine	Frequent	Absent	Absent	
FG13/21	A	0-10	10 YR 3/3	Moist	Sandy clay loam	Granular	Fine	Weak	Sandstone / Claystone	Gravel and stones	Subang.	molto Few to Frequent	Very fine	Common	Very fine to fine	Common	Abrupt	Smooth	
	B	10-40	10 YR 5/3	Moist	Silt clay loam	Sub. blocky	Fine	Weak	Sandstone / Claystone	Gravel and stones	Subang.	molto Few to Frequent	Very fine	Common	Very fine to fine	Common	Clear	Smooth	
	C	40-70+	10 YR 5/3	Moist	Sandy clay loam	Absent	Absent	Absent	Sandstone	Stones and boulders	Ang.	Abundant	Fine	Common	Very fine	Frequent	Absent	Absent	
FG13/22	A	0-14	10 YR 5/3	Dry	Silt loam	Absent	Absent	Absent	Sandstone	Gravel	Subang.	Few	Very fine to fine	Abundant	Very fine to fine	Common	Abrupt	Smooth	Sandstone stone line
	2Bt1	14-50	10 YR 5/4	Moist	Sandy clay	Sub. blocky	Medium	Strong	Sandstone	Gravel	Subang.	Few	Very fine	Very few	Very fine	Few	Clear	Smooth	Clay coatings
	2Bt2	50-70	10 YR 5/4	Moist	Sandy clay	Sub. blocky	Fine	Moderate	Sandstone	Gravel	Subang.	Few	Very fine	Very few	Very fine	Few	Abrupt	Smooth	Clay coatings
	2BC	70-80+	10 YR 5/4	Moist	Sandy clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Common	Absent	None	Absent	None	Absent	Absent	
FG13/23	A	0-15	10 YR 3/3	Dry	Silt loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Fine	Common	Very fine to fine	Common	Gradual	Smooth	
	Bw	15-80	10 YR 5/6	Dry	Silt clay loam	Sub. blocky	Medium	Weak	Claystone / Sandstone	Gravel	Flat/ Subang.	Few	Very fine	Few	Fine	Frequent	Clear	Wavy	Mottles
	Bg	80-90	2.5 Y 5/4	Moist	Sandy loam	Ang. blocky	Medium	Strong	Absent	Absent	Absent	Absent	Very fine	Few	Absent	None	Abrupt	Broken	
	Bgs	90-105	10 YR 5/6	Moist	Clay loam	Ang. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Few	Very fine	Few	Absent	None	Clear	Wavy	
	BC	105-140+	10 YR 5/3	Moist	Silt clay loam	Ang. blocky	Medium	Strong	Claystone / Sandstone	Gravel	Flat/ Subang.	Frequent	Very fine	Few	Absent	None	Absent	Absent	
FG13/24	A	0-18		Moist	Sandy clay loam	Granular	Fine	Strong	Claystone	Gravel	Flat	Frequent	Very fine to fine	Frequent	Very fine to fine	Common	Clear	Smooth	
	AB	18-30		Moist	Loam	Granular	Fine	Moderate	Claystone	Gravel	Flat	Few	Very fine	Very few	Very fine	Frequent	Clear	Smooth	
	2Bw	30-60		Moist	Clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Few	Very fine	Very few	Very fine	Few	Gradual	Smooth	
	2Bt	60-90		Moist	Clay loam	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Few	Very fine	Very few	Very fine	Few	Clear	Smooth	Clay coatings
	2BC	90-110+		Moist	Clay	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Frequent	Absent	None	Absent	None	Absent	Absent	
FG13/25	A1	0-12		Moist	Silt loam	Granular	Fine	Moderate	Claystone	Gravel	Flat	Frequent	Very fine to fine	Frequent	Fine	Common	Clear	Smooth	
	A2	12-24		Moist	Loam	Granular	Medium	Moderate	Claystone	Gravel	Flat	Frequent	Very fine	Few	Very fine to fine	Frequent	Clear	Wavy	
	B	24-44		Moist	Clay	Sub. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Very fine	Very few	Very fine to fine	Few	Gradual	Smooth	
	BC	44-61		Moist	Clay loam	Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Very few	Very fine	Very few	Very fine	Very few	Clear	Smooth	
	C	61-80+		Moist	Clay loam	Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Common	Absent	None	Absent	None	Absent	Absent	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
FG13/26	O	0-5	7.5 YR 4/3	Dry	Clay loam	Absent	Absent	Absent	Claystone	Gravel	Flat	Few	Very fine	Few	Fine	Common	Abrupt	Smooth	
	A1	5-24	7.5 YR 4/3	Dry	Sandy clay loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Very fine	Few	Very fine	Common	Abrupt	Smooth	
	A2	24-27	10 YR 4/4	Dry	Sandy clay	Granular	Fine	Moderate	Absent	Absent	Absent	Absent	Absent	None	Very fine	Frequent	Abrupt	Smooth	
	2Ab	27-30	5 YR 2/2	Dry	Sandy clay	Granular	Fine	Moderate	Absent	Absent	Absent	Absent	Absent	None	Very fine	Frequent	Abrupt	Smooth	
	3Bw1	30-37	7.5 YR 3/3	Moist	Clay loam	Granular	Fine	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Frequent	Absent	None	Very fine	Frequent	Abrupt	Smooth	Stone line
	3Bw2	37-47	7.5 YR 4/6	Moist	Sandy clay loam	Granular	Medium	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Few	Absent	None	Very fine	Few	Clear	Smooth	
	3Bw3	47-55	10 YR 4/6	Moist	Clay loam	Granular/ Sub. blocky	Medium	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Frequent	Absent	None	Very fine	Few	Clear	Smooth	
	3BC	55-80+	10 YR 5/4	Moist	Clay loam	Granular/ Sub. blocky	Medium	Moderate	Sandstone / Claystone	Gravel and stones	Subang. /Flat	Frequent	Absent	None	Very fine	Few	Absent	Absent	
FG13/27	O	0-7	10 YR 3/3	Dry	Clay loam	Granular	Fine	Weak	Claystone	Gravel	Flat	Very few	Very fine to fine	Frequent	Very fine to fine	Common	Clear	Smooth	
	A	7-14	10 YR 3/3	Moist	Loam	Granular	Fine	Moderate	Claystone	Gravel	Flat	Few	Very fine to fine	Few	Very fine	Common	Clear	Smooth	
	Bw1	14-35	10 YR 4/4	Moist	Silt loam	Granular/ Sub. blocky	Fine	Moderate	Claystone	Gravel	Flat	Few	Very fine	Few	Very fine	Frequent	Gradual	Smooth	
	Bw2	35-55	10 YR 4/4	Moist	Silt clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Very few	Very fine	Very few	Very fine	Few	Gradual	Smooth	
	Bt	55-100	10 YR 5/4	Moist	Silt clay loam	Sub. blocky	Coarse	Moderate	Claystone	Gravel	Flat	Very few	Very fine	Few	Very fine	Few	Clear	Smooth	Clay coatings
	BC	100-135 +	10 YR 5/3	Moist	Clay loam	Sub. blocky/ Ang.	Medium	Strong	Claystone	Gravel	Flat	Frequent	Very fine	Few	Absent	None	Absent	Absent	mottles
FG13/28	A	0-20	2.5 Y 4/4	Moist	Silt loam	Granular	Fine to medium	Moderate	Sandstone / Claystone	Gravel	Subang. /Flat	Few	Very fine to fine	Common	Very fine	Frequent	Clear	Smooth	
	Bt	20-50	2.5 Y 5/6	Moist	Silt clay loam	Sub. blocky	Medium	Strong	Sandstone / Claystone	Gravel and stones	Subang. /Flat	Frequent	Very fine to fine	Common	Very fine	Few	Clear	Smooth	Clay coatings
	CBt	50-90+	2.5 Y 5/4	Moist	Clay loam	Sub. blocky	Fine	Moderate	Sandstone / Claystone	Gravel and stones	Subang. /Flat	Frequent	Very fine to fine	Common	Medium	Very few	Absent	Absent	Clay coatings
F14/01	A	0-16	10 YR 3/3	Dry	Sandy loam	Granular	Fine	Weak	Sandstone	Gravel	Subang.	Few	Fine	Frequent	Fine to medium	Frequent	Clear	Smooth	
	Bw	16-53	10 YR 3/4	Moist	Loam	Sub. blocky	Fine	Weak	Sandstone	Gravel	Subang.	Few	Fine	Few	Very fine to fine	Few	Clear	Smooth	
	BC	53-80+	10 YR 4/4	Moist	Sandy clay loam	Ang. blocky	Medium	Moderate	Sandstone	Gravel and stones	Subang.	Common	Very fine	Very few	Very fine	Very few	Absent	Absent	
F14/02	O	0-4																	
	Bh	4-15	7.5 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Medium	Common	Fine to medium	Common	Clear	Smooth	
	Bs	15-47	7.5 YR 5/6	Moist	Silt clay loam	Sub. blocky	Fine	Weak	Sandstone	Gravel and stones	Subang.	Frequent	Fine	Frequent	Fine	Frequent	Clear	Smooth	
	BC	47-60+	10 YR 4/4	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Gravel and stones	Subang.	Common	Fine	Few	Very fine	Very few	Absent	Absent	
F14/03	A	0-35	7.5 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	Bw	35-55	10 YR 4/4	Moist	Loam	Granular	Fine	Weak	Sandstone	Gravel	Subang.	Frequent					Clear	Smooth	
	BC	55-75+	2.5 Y 5/4	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Gravel	Ang.	Frequent					Absent	Absent	
F14/04	A	0-20	10 YR 3/3	Moist													Clear	Smooth	
	Bw	20-60+	10 YR 4/4	Moist													Absent	Absent	
F14/05	O	0-10															Clear	Smooth	
	A	10-30	10 YR 3/3	Moist	Clay loam	Granular	Medium	Weak	Sandstone	Gravel	Flat	Very few					Clear	Smooth	
	AB	30-60	10 YR 4/4	Moist	Silt clay loam	Granular	Medium	Weak	Sandstone	Gravel	Flat	Few					Clear	Smooth	
	Bw	60-100	10 YR 4/6	Moist	Silty clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel and stones	Flat	Frequent					Gradual	Smooth	
	BC	100-120 +	10 YR 5/6	Moist	Clay	Ang. blocky	Medium	Moderate	Sandstone	Gravel, stones and boulders	Flat	Common					Absent	Absent	
F14/07	A	0-6	7.5 YR 2.5/2	Moist	Clay loam	Granular	Medium	Weak	Sandstone	Gravel	Subang.	Few	Fine	Frequent	Very fine to fine	Frequent	Clear	Smooth	
	2Ab	6-12	10 YR 2/2	Moist	Silty clay	Sub. blocky	Fine	Weak	Sandstone	Gravel	Subang.	Very few	Fine	Few	Fine	Few	Clear	Smooth	
	3Bw	12-40+	7.5 YR 4/3	Moist	Clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Very few	Very fine	Very few	Very fine	Very few	Absent	Absent	
F14/08	A	0-19	7.5 YR 4/4	Moist	Clay loam	Granular	Medium	Weak	Absent	Absent	Absent	Absent	Medium	Frequent	Fine	Frequent	Clear	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	AB	19-41	7.5 YR 4/3	Moist	Silty clay	Sub. blocky	Fine	Moderate	Absent	Absent	Absent	Absent	Fine	Frequent	Fine	Frequent	Clear	Smooth	
	Bw	41-70	7.5 YR 4/3	Moist	Sandy clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Few	Fine	Frequent	Fine	Frequent	Clear	Smooth	Mottles
	Bg	70-95+	10 YR 4/3	Moist	Sandy loam	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Few	Fine	Few	Absent	Absent	Absent	Absent	Mottles
F14/09	A	0-30	10 YR 3/3	Moist	Sandy clay loam	Granular	Fine	Moderate	Claystone	Gravel	Flat	Few			Very fine to fine	Frequent	Gradual	Smooth	
	Bt1	30-48	7.5 YR 4/6	Moist	Clay loam	Sub. blocky	Medium	Moderate	Claystone	Gravel	Flat	Few	Fine to medium	Common	Very fine to fine	Few	Clear	Smooth	Charcoals - Clay coatings
	Bt2	48-60	10 YR 4/6	Moist	Clay	Ang. blocky	Medium	Strong	Claystone	Gravel	Flat	Few	Very fine	Very few	Very fine to fine	Few	Clear	Wavy	
	Btg	60-80+	7.5 YR 5/6	Moist	Clay	Ang. blocky	Medium	Moderate	Claystone	Gravel	Flat	Frequent	Very fine	Very few	Fine to medium	Very few	Absent	Absent	Mottles
F14/10	A1	0-4	7.5 YR 4/2	Moist	Clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine to medium	Frequent	Medium	Common	Clear	Smooth	
	A2	4-12	7.5 YR 4/3	Moist	Sandy clay loam	Sub. blocky	Fine	Weak	Absent	Absent	Absent	Absent	Fine	Common	Fine to medium	Common	Clear	Smooth	
	Bw	12-27	10 YR 5/4	Moist	Clay	Sub. blocky	Medium	Moderate	Absent	Absent	Absent	Absent	Fine	Frequent	Fine	Few	Gradual	Smooth	
	BCg	27-50+	10 YR 5/4	Moist	Clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Frequent	Fine	Few	Fine	Few	Absent	Absent	Mottles
F14/11	A1	0-12	10 YR 3/4	Dry	Clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Medium	Frequent	Fine to medium	Common	Clear	Smooth	
	A2	12-32	10 YR 3/6	Moist	Clay	Granular	Fine	Weak	Sandstone	Gravel	Subrounded	Few	Fine	Common	Fine	Frequent	Clear	Smooth	
	2Bw	32-44	10 YR 5/6	Moist	Sandy clay	Sub. blocky	Medium	Moderate	Sandstone - Claystone	Gravel and stones	Subrounded-flat	Few	Medium	Frequent	Fine	Few	Clear	Smooth	Mottles
	2BCg	44-59	10 YR 5/4	Moist	Sandy clay loam	Ang. blocky	Medium	Strong	Sandstone	Gravel	Subrounded	Few	Very fine	Few	Fine	Few	Gradual	Smooth	Mottles
	2CBg	59-80+	10 YR 5/3	Moist	Sandy clay	Ang. blocky	Medium	Strong	Sandstone	Gravel	Subrounded	Few	Fine	Very few	Absent	Absent	Absent	Absent	Mottles
F14/12	A	0-15	10 YR 3/3	Moist	Clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine	Frequent	Fine	Few	Abrupt	Smooth	
	Bw	15-28	10 YR 4/4	Moist	Sandy clay	Sub. blocky	Medium	Moderate	Sandstone	Gravel	Subang.	Few	Fine	Frequent	Fine to medium	Few	Clear	Smooth	
	BC	28-65+	10 YR 4/3	Moist	Sandy clay loam	Sub. blocky	Medium	Weak	Sandstone	Gravel and stones	Subang.	Frequent	Fine	Frequent	Fine to medium	Frequent	Absent	Absent	
F14/13	O	0-8	10 YR 2/1	Dry	Silty clay	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine to medium	Abundant	Fine to medium	Common	Clear	Smooth	
	AE	8-12	10 YR 2/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Very fine to fine	Frequent	Fine to medium	Frequent	Abrupt	Smooth	
	Bh	12-17	10 YR 2/1	Moist	Loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Very fine to fine	Common	Fine	Abundant	Abrupt	Smooth	
	Bs1	17-23	7.5 YR 2.5/2	Moist	Loam	Granular	Medium	Moderate	Sandstone	Gravel	Subang.	Frequent	Fine	Common	Very fine	Frequent	Clear	Smooth	
	Bs2	23-46	10 YR 3/6	Moist	Sandy clay loam	Sub. blocky	Medium	Weak	Sandstone	Gravel and stones	Subang.	Frequent	Fine	Frequent	Fine	Few	Gradual	Smooth	
	BC	46-65+	2.5 Y 4/4	Moist	Silt loam	Ang. blocky	Medium	Moderate	Sandstone	Gravel and stones	Subang.	Common	Fine	Frequent	Fine	Few	Absent	Absent	
FG14/14	A	0-34	10 YR 4/4	Moist	Silt	Granular	Fine	Moderate	Sandstone - Claystone	Fine gravel	Flat	Very few	Fine	Few	Fine	Few	Abrupt	Smooth	
	AE	34-37	10 YR 4/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone - Claystone	Fine gravel	Flat	Very few	Fine	Few	Fine	Few	Abrupt	Smooth	
	2Ab	37-40	10 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone - Claystone	Fine gravel	Flat	Very few	Fine	Few	Fine	Few	Abrupt	Smooth	
	3Bw	40-48	10 YR 4/6	Moist	Loam	Granular	Medium	Moderate	Sandstone - Claystone	Medium gravel	Flat	Common	Fine to medium	Few	Very fine to fine	Very few	Abrupt	Smooth	
	3BC	48-80+	10 YR 5/4	Moist	Silt clay loam	Sub. blocky	Fine	Moderate	Sandstone - Claystone	Coarse gravel and stones	Flat	Frequent	Fine	Few	Very fine	Very few	Absent	Absent	
FG14/15	AC	0-55	10 YR 5/4	Moist	Sandy loam	Granular	Fine	Moderate	Sandstone - Claystone	Medium gravel	Flat	Frequent	Fine to medium	Frequent	Fine	Few	Clear	Smooth	
	BC	55-75	10 YR 4/4	Moist	Loam	Granular	Medium	Moderate	Sandstone - Claystone	Medium gravel	Flat	Few	Fine	Few	Very fine	Very few	Clear	Smooth	
	2AC	75-100	10 YR 5/4	Moist	Loam	Sub. blocky	Fine	Moderate	Sandstone - Claystone	Medium gravel	Flat	Frequent	Fine to medium	Few	Absent	Absent	Clear	Smooth	
	2BC	100-120+	10 YR 5/4	Moist	Silt clay loam	Ang. blocky	Medium	Moderate	Sandstone - Claystone	Fine gravel	Flat	Very few	Very fine	Few	Absent	Absent	Absent	Absent	
FG14/16	O	0-4															Abrupt	Smooth	
	A	4-17	10 YR 3/4	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Broken	
	2Ab	17-20	7.5 YR 4/2	Moist	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Broken	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	3Bw	20-27	10 YR 4/4	Moist	Loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Broken	
	4Ab	27-34	7.5 YR 4/2	Moist	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	5Bw	34-45	10 YR 4/6	Moist	Silt loam	Granular	Medium	Moderate	Sandstone	Medium gravel	Subang.	Frequent					Gradual	Smooth	
	5BC	45-65+	2.5 Y 5/4	Moist	Sandy loam	Granular	Medium	Moderate	Sandstone	Medium gravel	Subang.	Frequent					Absent	Absent	
FG14/17	A	0-20	10 YR 4/4	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	AE	20-28	7.5 YR 4/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Broken	
	2Ab	28-35	7.5 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	3Bw1	35-50	7.5 YR 3/4	Moist	Loam	Granular	Medium	Moderate	Sandstone	Coarse gravel and stones	Subang.	Frequent					Clear	Smooth	
	3Bw2	50-70	10 YR 4/6	Moist	Loam	Granular	Medium	Weak	Sandstone	Coarse gravel and stones	Subang.	Frequent					Clear	Smooth	
	3BC	70-80+	10 YR 5/6	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Frequent					Absent	Absent	
FG14/18	O	0-4															Abrupt	Smooth	
	A	4-12	10 YR 3/3	Moist	Clay loam	Granular	Fine	Weak	Claystone	Fine gravel	Flat	Very few			Fine to medium	Frequent	Abrupt	Smooth	Charcoals and charcoals pouch
	2Bw1	12-27	10 YR 4/4	Moist	Silty clay	Granular	Medium	Moderate	Claystone	Fine gravel	Flat	Few			Fine	Few	Clear	Smooth	
	2Bw2	27-37	10 YR 4/3	Moist	Silty clay	Sub. blocky	Fine	Strong	Claystone	Fine gravel	Flat	Frequent			Fine	Very few	Clear	Smooth	
	2CB	37-48	10 YR 4/3	Moist	Clay	Ang. blocky	Fine	Strong	Claystone	Coarse gravel and stones	Flat	Abundant			Absent	Absent	Clear	Smooth	
	2C	48-50+															Absent	Absent	
FG14/19	O1	0-6	7.5 YR 2.5/2	Moist													Abrupt	Wavy	
	O2	6-12	7.5 YR 2.5/1	Moist													Abrupt	Wavy	
	A	12-32	10 YR 2/2	Moist	Silt loam	Sub. blocky	Medium	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	Bw	32-40	10 YR 4/4	Moist	Silt clay loam	Sub. blocky	Medium	Moderate	Sandstone	Fine and medium gravel	Flat	Few					Clear	Smooth	
	CB	40-60	10 YR 4/4	Moist	Silt clay loam	Ang. blocky	Fine	Moderate	Sandstone	Coarse gravel and stones	Flat	Common					Clear	Smooth	
	C	60-65+															Absent	Absent	
FG14/20	O	0-2															Abrupt	Smooth	
	A1	2-22	10 YR 3/4	Moist	Sandy clay	Granular	Medium	Moderate	Claystone	Fine gravel	Flat	Few	Medium	Frequent	Fine to medium	Common	Gradual	Smooth	
	A2	22-35	10 YR 4/4	Moist	Sandy clay	Granular	Medium	Moderate	Sandstone - Claystone	Fine gravel and stones	Subang. -flat	Few	Medium	Common	Fine to medium	Frequent	Clear	Smooth	
	Bt	35-55	10 YR 5/4	Moist	Clay	Sub. blocky	Medium	Weak	Sandstone - Claystone	Fine gravel and stones	Subang. -flat	Frequent	Fine	Few	Fine to medium	Few	Clear	Smooth	
	BCt	55-75+	10 YR 6/6	Moist	Clay	Ang. blocky	Medium	Strong	Sandstone - Claystone	Fine gravel and stones	Ang.-flat	Few to common	Very fine	Very few	Fine	Few	Absent	Absent	
FG14/21	A	0-15	10 YR 4/4	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Medium gravel	Flat	Few	Fine	Common	Fine to medium	Frequent	Clear	Wavy	
	Bw	15-45	10 YR 4/6	Moist	Silt loam	Granular	Medium	Moderate	Sandstone	Coarse gravel	Subrounded	Frequent	Fine	Frequent	Fine to medium	Frequent	Gradual	Smooth	
	BC	45-115+	10 YR 5/6	Moist	Silt loam	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Very fine to fine	Few	Fine to medium	Very few	Absent	Absent	Mottles
FG14/22	A1	0-30	10 YR 5/4	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Medium gravel	Subang.	Few					Clear	Smooth	
	A2	30-50	10 YR 5/6	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Coarse gravel	Subang.	Few					Clear	Smooth	
	Bw	50-100+	10 YR 4/6	Moist	Loam	Sub. blocky	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Frequent					Absent	Absent	
FG14/23	O	0-20															Clear	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	A	20-45	7.5 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent	Fine	Few	Fine to medium	Frequent	Abrupt	Smooth	
	2A	45-65	10 YR 2/2	Moist	Silt loam	Sub. blocky	Fine	Weak	Sandstone	Fine gravel	Subang.	Very few	Fine	Very few	Very fine to fine	Few	Clear	Smooth	
	2Bw	65-80	10 YR 3/3	Moist	Silt loam	Sub. blocky	Medium	Moderate	Sandstone	Fine gravel	Subang.	Very few	Fine	Very few	Very fine to fine	Few	Gradual	Smooth	
	2BC	80-100+	10 YR 3/4	Moist	Loam	Sub. blocky	Medium	Moderate	Sandstone	Coarse gravel	Subang.	Common	Very fine	Few	Absent	Absent	Absent	Absent	
FG14/24	O	0-5															Abrupt	Smooth	
	AB	5-30	10 YR 4/4	Moist	Clay loam	Granular	Medium	Moderate	Claystone	Fine gravel	Flat	Frequent	Fine to medium	Frequent	Fine to medium	Frequent	Gradual	Smooth	
	Bt	30-85	10 YR 4/6	Moist	Clay	Ang. blocky	Medium	Moderate	Claystone	Fine gravel	Flat	Few	Fine	Few	Medium	Few	Clear	Smooth	
	BC	85-100+	10 YR 5/6	Moist	Clay	Ang. blocky	Medium	Strong	Claystone	Fine gravel	Flat	Frequent	Very fine	Very few	Medium	Few	Absent	Absent	
FG14/25	AC	0-25	10 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Frequent	Fine	Few	Fine	Few	Abrupt	Smooth	
	2O	25-45	10 YR 3/2	Moist	Silt clay loam	Granular	Fine	Weak	Sandstone	Coarse gravel	Subang.	Few	Fine to medium	Abundant	Fine to medium	Abundant	Clear	Smooth	
	2AC	45-100+	10 YR 3/3	Moist	Silt loam	Granular	Medium	Moderate	Sandstone	Coarse gravel and stones	Subang.	Frequent	Fine	Frequent	Fine	Frequent	Absent	Absent	
FG14/26	A	0-8	10 YR 3/4	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Coarse gravel	Subang.	Frequent	Fine	Frequent	Fine	Few	Clear	Smooth	
	Bw	8-75	10 YR 4/6	Moist	Sandy clay loam	Granular	Medium	Weak	Sandstone	Coarse gravel and stones	Subang.	Common	Fine	Few	Fine to medium	Few	Diffuse	Smooth	
	BtC	75-120+	10 YR 5/6	Moist	Sandy clay	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Very fine	Few	Fine	Very few	Absent	Absent	
FG14/27	O	0-10															Clear	Smooth	
	A	10-45	7.5 YR 5/6	Dry	Sandy loam	Granular	Fine	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Medium	Common	Fine to medium	Common	Gradual	Smooth	
	Bw1	45-110	10 YR 5/6	Moist	Loam	Granular	Fine	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Fine to medium	Frequent	Fine to medium	Frequent	Diffuse	Smooth	
	Bw2	110-160	10 YR 5/4	Moist	Loam	Granular	Fine	Moderate	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Fine	Few	Medium	Very few	Clear	Smooth	
	BC	160-180 +	10 YR 5/3	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Common	Fine	Few	Absent	Absent	Absent	Absent	
FG14/28	O	0-2															Abrupt	Smooth	
	Bw	2-30	10 YR 4/6	Moist	Silt loam	Granular	Fine	Moderate	Sandstone	Fine gravel	Subang.	Few	Fine to medium	Frequent	Fine to medium	Frequent	Clear	Smooth	
	2AC	30-50	10 YR 4/4	Moist	Silt clay loam	Granular	Medium	Weak	Sandstone	Coarse gravel and stones	Subrounded-flat	Abundant	Fine	Frequent	Fine to medium	Few	Clear	Smooth	
	2BC	50-120+	10 YR 4/4	Moist	Clay loam	Granular	Medium	Weak	Sandstone	Coarse gravel, stones and boulders	Subrounded-flat	Common	Fine	Frequent	Fine	Few	Absent	Absent	
FG14/29	O	0-10															Clear	Smooth	
	A	10-35	10 YR 4/3	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	2Ab	35-39	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	2Bw	39-42	10 YR 3/4	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	3Ab	42-47	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	3Bw	47-50	10 YR 3/4	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	4Ab	50.54	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	4Bw	54-57	10 YR 3/4	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	5Ab	57-60	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	5Bw1	60-67	10 YR 4/4	Moist	Silt loam	Sub. blocky	Medium	Weak	Sandstone	Fine gravel	Subrounded	Very few					Gradual	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	5Bw2	67-86	10 YR 3/4	Moist	Silt clay loam	Sub. blocky	Medium	Weak	Sandstone	Fine gravel	Subrounded	Very few					Clear	Smooth	
	C	86-95+															Absent	Absent	
FG14/30	A	0-6	10 YR 3/4	Dry	Sandy loam	Granular	Fine	Weak	Sandstone	Fine gravel	Subang.	Few					Abrupt	Smooth	
	C	6-10+															Absent	Absent	
FG14/31	O	0-14															Clear	Smooth	
	A	14-30	10 YR 3/3	Moist	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	BC	30-36	10 YR 4/4	Moist	Silty clay	Sub. blocky	Fine	Weak	Marlstone	Coarse gravel	Flat	Frequent					Clear	Smooth	
	C	36-60+	10 YR 5/6														Absent	Absent	
FG14/32	O	0-7															Abrupt	Smooth	
	A	7-21	10 YR 3/3	Moist	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	Bw	21-32	10 YR 4/2	Moist	Silty clay	Sub. blocky	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	BC	32-40	10 YR 4/4	Moist	Silty clay	Sub. blocky	Fine	Weak	Marlstone	Coarse gravel	Flat	Frequent					Clear	Smooth	
	C	40-50+	10 YR 5/6														Absent	Absent	
FG14/33	O	0-4															Abrupt	Smooth	
	A	4-13	10 YR 3/3	Moist	Silt clay loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	Bw	13-24	10 YR 4/2	Moist	Silty clay	Sub. blocky	Fine	Weak	Sandstone	Coarse gravel	Subang.	Frequent					Clear	Smooth	
	BC	24-35	10 YR 4/4	Moist	Silty clay	Sub. blocky	Fine	Weak	Sandstone	Coarse gravel	Subang.	Frequent					Abrupt	Smooth	
	C	35-50+	10 YR 5/6														Absent	Absent	
FG14/34	O	0-2															Abrupt	Smooth	
	A	2-12	10 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent					Clear	Smooth	
	AC	12-28	10 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone - Marlstone	Coarse gravel and stones	Subang.	Common					Clear	Smooth	
	BC	28-38	10 YR 4/4	Moist	Silt loam	Sub. blocky	Fine	Weak	Sandstone - Marlstone	Coarse gravel and stones	Subang.	Few					Clear	Smooth	
	2C	38-60+	2.5 Y 5/3	Moist													Absent	Absent	
FG14/35	O	0-3															Abrupt	Smooth	
	A1	3-11	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Sandstone	Fine gravel	Subang.	Few					Clear	Smooth	
	A2	11-23	7.5 YR 3/4	Moist	Loam	Granular	Fine	Weak	Sandstone	Medium gravel	Subang.	Frequent					Clear	Smooth	
	AB	23-40	7.5 YR 4/4	Moist	Loam	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Frequent					Clear	Smooth	
	CB	40-60	10 YR 4/3	Moist	Loam	Ang. blocky	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Common					Gradual	Smooth	
	C	60-65+															Absent	Absent	
FG14/36	O	0-7															Abrupt	Smooth	
	A	7-70	2.5 Y 4/2	Dry	Sandy loam	Granular	Medium	Moderate	Claystone	Fine gravel and stones	Flat	Few to Frequent	Fine	Frequent	Very fine to fine	Few	Gradual	Smooth	
	AB	70-130	2.5 Y 4/3	Moist	Sandy clay loam	Sub. blocky	Medium	Moderate	Claystone	Fine gravel and stones	Flat	Few to Frequent	Fine	Frequent	Very fine	Very few	Clear	Smooth	
	2Bt1	130-160	10 YR 4/3	Moist	Silty clay	Ang. blocky	Medium	Strong	Claystone	Fine gravel	Flat	Few	Fine	Few	Absent	Absent	Abrupt	Smooth	
	2Bt2	160-170	10 YR 4/6	Moist	Silty clay	Ang. blocky	Coarse	Strong	Claystone	Fine gravel	Flat	Few	Fine	Few	Absent	Absent	Clear	Smooth	
	2Bt3	170-185	10 YR 4/4	Moist	Silty clay	Ang. blocky	Coarse	Strong	Claystone	Fine gravel	Flat	Few	Fine	Few	Absent	Absent	Clear	Smooth	
	2BtC	185-210	10 YR 5/3	Moist	Silty clay	Ang. blocky	Medium	Strong	Claystone	Fine gravel	Flat	Frequent	Very fine	Very few	Absent	Absent	Clear	Smooth	
	2C	210-220+															Absent	Absent	
FG14/37	O	0-10															Abrupt	Smooth	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
	A1	10-16	10 YR 3/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent			Fine	Frequent	Abrupt	Smooth	
	A2	16-22	10 YR 2/2	Moist	Sandy loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent			Fine	Frequent	Abrupt	Smooth	
	2BC	22-40	10 YR 3/4	Moist	Silt loam	Absent	Absent	Absent	Sandstone	Coarse gravel and stones	Subang.	Common			Fine	Frequent	Abrupt	Smooth	
	2C	40-45+															Absent	Absent	
FG14/38	O	0-12															Clear	Smooth	
	AC	12-60	10 YR 5/3	Moist	Loam	Granular	Medium	Moderate	Claystone	Coarse gravel	Flat	Frequent			Very fine	Few	Gradual	Smooth	
	BC	60-80	2.5 Y 5/3	Moist	Clay loam	Ang. blocky	Medium	Moderate	Claystone	Coarse gravel	Flat	Common			Absent	Absent	Gradual	Smooth	
	C	80-120+															Absent	Absent	
FG14/39	O	0-3															Abrupt	Smooth	
	A	3-5	7.5 YR 3/2	Moist	Loam	Granular	Fine	Moderate	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	B1	5-11	7.5 YR 4/4	Moist	Silt loam	Granular	Medium	Moderate	Absent	Absent	Absent	Absent					Abrupt	Smooth	
	B2	11-21	7.5 YR 4/5	Moist	Loam	Sub. blocky	Fine	Weak	Sandstone	Coarse gravel	Subang.	Few					Abrupt	Smooth	
	CB	21-30+	7.5 YR 4/4	Moist	Silt clay loam	Sub. blocky	Medium	Moderate	Sandstone	Coarse gravel, stones and boulders	Subang.	Common					Absent	Absent	
FG14/40	O	0-5															Abrupt	Smooth	
	A	5-30	10 YR 3/3	Moist	Silt	Granular	Fine	Weak	Absent	Absent	Absent	Absent			Very fine to fine	Frequent	Clear	Smooth	
	Bw	30-60	10 YR 3/4	Moist	Silty clay	Sub. blocky	Fine	Moderate	Sandstone	Coarse gravel	Subang.	Few			Very fine	Few	Diffuse	Smooth	
	BC	60-100	10 YR 3/6	Moist	Loam	Granular	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Common			Absent	Absent	Clear	Smooth	
	C	100-110 +															Absent	Absent	
FG14/41	O	0-4															Abrupt	Smooth	
	A	4-20	10 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone	Fine and medium gravel	Subang.	Few			Fine to medium	Frequent	Clear	Smooth	
	Bw1	20-55	10 YR 3/4	Moist	Silt clay loam	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel and stones	Subang.	Few			Fine	Few	Gradual	Smooth	
	Bw2	55-75	10 YR 3/4	Moist	Silty clay	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel, stones and boulders	Subang.	Frequent			Fine	Few	Clear	Smooth	
	BC	75-100+	10 YR 5/4	Moist	Silty clay	Ang. blocky	Fine	Moderate	Sandstone	Coarse gravel, stones and boulders	Subang.	Frequent			Very fine	Very few	Absent	Absent	
FG14/42	O	0-3															Clear	Smooth	
	Bw	3-33	10 YR 4/6	Moist	Silty clay	Sub. blocky	Medium	Moderate	Sandstone - Claystone	Fine gravel	Subang.	Few			Fine to medium	Frequent	Clear	Smooth	
	BCt	33-55	10 YR 5/3	Moist	Clay	Ang. blocky	Medium	Moderate	Sandstone - Claystone	Coarse gravel	Subang.	Frequent			Medium	Few	Clear	Smooth	
	CB	55-75	10 YR 5/4	Moist	Sandy clay	Ang. blocky	Medium	Strong	Sandstone - Claystone	Coarse gravel and stones	Subang.	Common			Absent	Absent	Clear	Smooth	
	C	75-85+															Absent	Absent	
FG14/43	O	0-10															Clear	Smooth	
	A	10-28	10 YR 4/4	Dry	Silt clay loam	Granular	Fine	Weak	Claystone	Fine gravel	Flat	Frequent			Fine to medium	Frequent	Gradual	Smooth	
	AB	28-40	10 YR 4/3	Moist	Silt clay loam	Sub. blocky	Fine	Weak	Claystone	Fine gravel	Flat	Frequent			Fine	Few	Abrupt	Smooth	
	2Ab	40-45	10 YR 3/3	Moist	Silty clay	Granular	Fine	Weak	Claystone	Fine gravel	Flat	Few			Very fine	Very few	Clear	Smooth	
	3Bw	45-56	10 YR 3/3	Moist	Silt	Granular	Medium	Weak	Claystone	Fine and medium gravel	Flat	Few			Very fine	Very few	Abrupt	Smooth	
	3BC	56-70	10 YR 5/3	Moist	Loam	Sub. blocky	Fine	Weak	Claystone	Fine gravel	Flat	Frequent			Very fine	Very few	Clear	Smooth	
	2C	70-75+															Absent	Absent	

Profile	Horizon	Depth (cm)	Colour	Soil moisture	Texture	Structure	Str. size	Str. pedality	Coarse fraction	C.f. size	C.f. shape	C.f. frequency	Pores size	Pores frequency	Root size	Root frequency	Bound. distinctness	Bound. topography	Other features
FG14/44	O	0-5															Clear	Smooth	
	A1	5-30	10 YR 5/3	Moist	Silt loam	Granular	Medium	Moderate	Marlstone	Fine gravel	Flat	Few			Very fine	Few	Gradual	Smooth	
	A2	30-50	10 YR 5/4	Moist	Silt	Granular	Medium	Moderate	Marlstone	Fine gravel	Flat	Few			Very fine	Very few	Clear	Smooth	
	C	50-60+															Absent	Absent	
FG14/45	O	0-9															Clear	Smooth	
	A	9-32	10 YR 5/3	Moist	Silt loam	Granular	Fine	Moderate	Claystone	Fine gravel	Flat	Frequent			Very fine to fine	Few	Abrupt	Smooth	
	2Ab	32-36	10 YR 3/3	Moist	Silty clay	Granular	Medium	Weak	Absent	Absent	Absent	Absent			Very fine	Few	Clear	Smooth	
	3Bw	36-43	10 YR 4/3	Moist	Silty clay	Granular	Fine	Weak	Claystone	Fine gravel	Flat	Very few			Very fine	Few	Abrupt	Smooth	
	3CB	43-60+	10 YR 4/3	Moist	Silt	Granular	Medium	Weak	Claystone	Coarse gravel and stones	Flat	Common			Absent	Absent	Absent	Absent	
FG14/46	O	0-6															Abrupt	Smooth	
	A	6-11	7.5 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Absent	Absent	Absent	Absent			Fine to medium	Frequent	Abrupt	Smooth	
	Bh	11-25	7.5 YR 3/2	Moist	Silt loam	Granular	Fine	Weak	Sandstone	Coarse gravel	Subang.	Few			Fine	Few	Clear	Smooth	
	Bs	25-35	7.5 YR 3/4	Moist	Silt clay loam	Granular	Fine	Moderate	Sandstone	Fine and medium gravel	Subang.	Few			Very fine	Few	Gradual	Smooth	
	CB	35-55+	2.5 Y 5/4	Moist	Silty clay	Ang. blocky	Fine	Weak	Sandstone	Coarse gravel and stones	Subang.	Frequent			Very fine	Very few	Absent	Absent	
FG14/47	A	0-10	10 YR 4/2	Dry	Silt loam	Granular	Fine	Weak	Sandstone	Medium gravel	Flat	Frequent			Fine	Frequent	Clear	Smooth	
	AB	10-35	10 YR 4/2	Moist	Silt clay loam		Medium	Moderate	Sandstone - Claystone	Coarse gravel, stones and boulders	Flat	Frequent			Fine	Frequent	Clear	Smooth	
	Bw	35-55	10 YR 4/4	Moist	Silt clay loam		Fine	Moderate	Sandstone - Claystone	Coarse gravel, stones and boulders	Flat	Frequent			Very fine to fine	Few	Gradual	Smooth	
	BC	55-75	10 YR 3/4	Moist	Silt clay loam		Medium	Weak	Sandstone - Claystone	Coarse gravel, stones and boulders	Flat	Frequent			Very fine	Very few	Clear	Smooth	
	C	75-85+															Absent	Absent	
FG14/48	O	0-15															Clear	Smooth	
	A	15-30	7.5 YR 3/3	Moist	Silt loam	Granular	Fine	Weak	Sandstone	Fine and medium gravel	Subang.	Few			Fine to medium	Frequent	Clear	Smooth	
	Bw	30-50	10 YR 3/4	Moist	Loam	Sub. blocky	Medium	Weak	Sandstone	Coarse gravel	Subang.	Few			Fine	Few	Gradual	Smooth	
	BC	50-85+	10 YR 3/6	Moist	Sandy loam	Ang. blocky	Fine	Weak	Sandstone	Coarse gravel	Subang.	Frequent			Fine	Very few	Absent	Absent	

11.2 - Appendix 2 - Micromorphological features of thin sections

Fine material: clay and fine silt; l. p.: lower part; u.p.: upper part; abundance: very dominant: >70%; dominant: 50-70%; frequent: 30-50%; common: 15-30; few: 5-15%; very few: <5%.

Horizon	**F13/03 - 3Bw-3Bt**	**F13/03 - 3Bt-3BC**	**F13/04 - AB**
Microstructure	Granular	Subangular blocky	Granular
Aggregates	Dominant weakly separated granular, fine sand size	Very dominant weakly separated subangular blocky, gravel to very coarse sand size	Dominant moderately separated granular, fine to very fine sand size
Porosity	Frequent complex packing voids, few channels, few star shaped vughs	Very few linear planes and channels	Common complex packing voids, few channels, very few star shaped vughs
c/f limit - c/f ratio	5 µm - 30/70 (5/95 in the l.p.)	5 µm - 10/90	10 µm - 40/60
c/f related distribution	Open porphyric	Open porphyric	Fine single-spaced enaulic, locally double-spaced porphyric
Mineral fragments	Frequent moderately weathered subangular sandstones and claystones	Few variably weathered rounded claystones in the l.p.	Frequent weakly weathered subrounded claystones
Fine material	Brown speckled/cloudy	Reddish-brown cloudy	Brown opaque
b-Fabric	Stipple speckled, reddish brown (grayish-brown in the l.p.)	Stipple speckled and granostriated, locally striated, reddish-brown	Stipple speckled, locally granostriated, brown-reddish
Vegetal material	Very few plant residues (roots)	-	Very few plant residues (roots)
Pedofeatures	Very few subrounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few fabric hypocoatings (compaction); frequent matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few typic-crescent microlaminated dusty clay coatings; very few fabric hypocoatings (reorientation); very few matrix infillings	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fragmented impure clay infillings; very few fabric hypocoatings (compaction); frequent matrix infillings

	F13/04 - 2Ab	**F13/04 - 3Bt-3BC**	**F13/05 - A1-A2**
Microstructure	Granular	Complex, subangular blocky/channel	Granular (subangular blocky in the l.p.)
Aggregates	Very dominant moderately-weakly separated granular, very fine sand to silt size	Dominant weakly separated subangular blocky, gravel to coarse sand size; frequent weakly separated granular, very fine sand size	Common moderately separated granular, coarse to very fine sand size, in the u.p.; very dominant highly separated subangular blocky, gravel to very coarse sand size, in the l.p.
Porosity	Frequent complex packing voids, very few linear planes (vertical in the u.p.)	Few vughs, very few linear planes	Frequent (very few in the l.p.) complex packing voids, few linear planes and channels
c/f limit - c/f ratio	5 µm - 5/95	5 µm - 5/95	10 µm - 45/55 (20/80 in the l.p.)
c/f related distribution	Open fine enaulic	Open porphyric	Fine single-spaced enaulic (double-spaced porphyric in the l.p.)
Mineral fragments	Very few strongly weathered rounded claystones and sandstones	Very few weakly weathered (strongly in the l.p.) rounded claystones and subangular sandstones	Common (few in the l.p.) moderately weathered subrounded claystones
Fine material	Brown-reddish speckled	Brown-yellowish speckled (yellowish cloudy in the l.p.)	Brown speckled
b-Fabric	Stipple speckled, grey	Stipple speckled and grano-porostriated, brown-yellowish brown (stipple speckled, striated-granostriated, yellowish-greyish in the l.p.)	Stipple speckled, reddish-brown
Vegetal material	Very few plant residues (roots) and charcoals	Very few charcoals	Very few plant residues (roots) and charcoals
Pedofeatures	Very few subrounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few matrix infillings	Very few subrounded-irregular alteromorphic and typic nodules of Fe-Mn with clear boundary; very few nonlaminated typic (microlaminated crescent in the l.p.) clay and silt coatings; very few matrix infillings	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; few matrix infillings

	F13/05 - A2-2Ab	**F13/05 - 3Bw-3Bt**	**F13/05 - 3Bt**
Microstructure	Granular	Complex, granular/subangular blocky (channel in the l.p.)	Subangular blocky
Aggregates	Dominant highly separated granular, silt size	Common (very dominant in the l.p.) highly separated subangular blocky, gravel to coarse sand size; common (few in the l.p.) weakly separated granular, fine sand size	Very dominant moderately separated subangular blocky, gravel to very coarse sand size; very few weakly separated granular, very fine sand size
Porosity	Common complex packing voids, very few linear planes locally horizontal-vertical	Frequent complex packing voids in the u.p., few linear planes in the l.p., very few channels and vughs	Few vughs, very few linear planes, compound packing voids and channels
c/f limit - c/f ratio	5 µm - 5/95 (15/85 in the u.p.)	5 µm - 15/85	5 µm - 20/80
c/f related distribution	Fine open enaulic	Open porphyric	Open porphyric
Mineral fragments	Very few moderately weathered rounded claystoned in the u.p.	Very few moderately weathered subangular claystones	Few moderately weathered rounded claystones
Fine material	Brown speckled (yellowish in the u.p.)	Reddish-brown cloudy	Reddish-brown cloudy
b-Fabric	Stipple speckled, reddish brown (yellowish-brown in the u.p.)	Stipple speckled, reddish brown (granostriated, yellowish brown in the l.p.)	Stipple speckled, yellowish-brown
Vegetal material	Very few plant residues (roots) and charcoals	Very few plant residues (roots) and charcoals	-

Pedofeatures	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction) and matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with clear boundary; very few nonlaminated clay and silt coatings in he l.p.; few matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with clear boundary; very few nonlaminated clay and silt coatings and infillings, microlaminated dusty clay coatings; frequent matrix infillings
	F13/06 - AB-2Ab	**F13/06 - 3Bt**	**F13/07 - 2Ab-3Bw**
Microstructure	Primary granular, secondary angular blocky	Subangular blocky	Granular
Aggregates	Dominant-common highly separated granular, very fine sand to silt size; dominant weakly separated angular blocky, gravel size; very few clayey pedorelicts, gravel to coarse sand size	Dominant highly separated subangular blocky, gravel to medium sand size	Very dominant highly separated granular, very fine sand to silt size; common moderately separated subangular blocky, coarse to fine sand size
Porosity	Common complex packing voids, few linear planes locally horizontal-vertical	Frequent linear planes, very few channels	Common complex packing voids, few linear planes locally horizontal-vertical
c/f limit - c/f ratio	5 µm - 10/90 (40/60 in the u.p., locally up to 70/30)	5 µm - 20/80	5 µm - 10/90
c/f related distribution	Open porphyric (fine open enaulic in the u.p.)	Open porphyric	Open porphyric (fine open enaulic in the u.p.)
Mineral fragments	Frequent weakly weathered subrounded claystones	Few variably weathered rounded claystones	Few weakly weathered subrounded claystones
Fine material	Brown speckled (brown-yellowish in the l.p.)	Reddish-brown cloudy	Yellowish brown speckled (brown-reddish in the l.p.)
b-Fabric	Stipple speckled, brown-yellowish brown (greyish-dark reddish in the l.p.)	Striated and grano-porostriated, reddish-brown	Stipple speckled, grayish brown (reddish in the l.p.)
Vegetal material	Very few plant residues (roots) and charcoals	Very few charcoals	Very few plant residues (roots) and charcoals
Pedofeatures	Very few rounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few nonlaminated typic or microlaminated impure clay infillings-crescents; very few fabric hypocoatings (reorientation); few matrix infillings	Very few rounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)
	F13/08 - AB	**F13/08 - 2Bt**	**F13/10 - AB**
Microstructure	Complex, granular/subangular blocky	Subangular blocky	Complex, granular/subangular blocky
Aggregates	Dominant-frequent highly separated granular, very fine sand size; frequent highly separated subangular blocky, coares to fine sand size; very few clayey pedorelicts, gravel to coarse sand size	Dominant moderately separated subangular blocky, gravel to medium sand size; few weakly separated granular, medium to fine sand size	Frequent moderately separated granular, very fine sand to silt size; few highly separated subangular blocky, gravel to very coarse sand size
Porosity	Common complex packing voids, few channels, very few star shaped vughs	Few channels, few vughs, few linear planes	Frequent vughs (few star shaped), few complex packing voids
c/f limit - c/f ratio	10 µm - 15/85	5 µm - 15/85	10 µm - 50/50
c/f related distribution	Open porphyric	Open porphyric	Close porphyric
Mineral fragments	Few weakly weathered subangular sandstones	Very few weakly weathered subrounded sandstones	Common weakly-moderately weathered subrounded claystones
Fine material	Yellowish brown speckled	Brown-yellowish speckled	Grey-brownish speckled
b-Fabric	Stipple speckled, yellowish brown	Grano-porostriated, yellowish brown (striated the l.p.)	Stipple speckled, yellowish-grey
Vegetal material	Very few plant residues (roots)	-	Very few plant residues (roots)
Pedofeatures	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)	Very few subrounded alteromorphic and typic nodules of Fe-Mn with clear boundary; very few microlaminated crescent typic impure clay coatings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; few matrix infillings
	F13/10 - 2Bw	**F13/10 - 3Bt**	**F13/10 - 3Btg**
Microstructure	Complex, granular/subangular blocky	Complex, subangular blocky/channel	Subangular blocky
Aggregates	Common moderately separated granular, very fine sand to silt size; frequent highly separated subangular blocky, gravel to coarse sand size	Dominant highly separated subangular blocky, gravel size; few highly separated granular, very fine sand to silt size	Very dominant highly separated subangular blocky, gravel to very coarse sand size
Porosity	Frequent star shaped vughs, few channels	Very few channels and linear planes	Few linear planes and channels, very few vughs
c/f limit - c/f ratio	10 µm - 20/80	5 µm - 25/75	5 µm - 15/85
c/f related distribution	Double-spaced porphyric	Single-spaced porphyric	Open porphyric
Mineral fragments	Few moderately weathered rounded claystones and subrounded sandstones	Frequent strongly weathered rounded claystones	Few moderately weathered subrounded claystones and sandstones
Fine material	Yellowish-brown speckled-cloudy	Reddish-brown cloudy	Brown (yellowish in the u.p.) speckled-cloudy
b-Fabric	Stipple speckled (locally grano-porostriated), yellowish-grey	Stipple speckled and grano-porostriated (locally striated), reddish-brown	Stipple speckled, reddish-brown (locally striated, yellowish-grey in the u.p.)
Vegetal material	Very few plant residues (roots) and charcoals	Very few plant residues (roots)	Very few plant residues (roots)
Pedofeatures	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; few matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few microlaminated dusty clay coatings; very few coalescent excrements	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few microlaminated limpid-dusty clay infillings-crescents; very few depletion coatings and matrix infillings
	F13/10 - 3BtC	**F13/12 - AB**	**F13/12 - 2Bw1**

Microstructure	Channel	Subangular blocky	Complex, subangular blocky/channel
Aggregates	Very dominant moderately separated subangular blocky, gravel to very coarse sand size; very few clayey pedorelicts, fine to very fine sand size	Dominant highly separated subangular blocky, very coarse to coarse sand size; common moderately separated granular, very fine sand size	Dominant highly separated subangular blocky, gravel to fine sand size; very few moderately separated granular, very fine sand size; very few clayey pedorelicts, gravel to coarse sand size
Porosity	Few linear planes, very few vughs and channels	Few channels, very few complex packing voids	Frequent channels, few vughs
c/f limit - c/f ratio	5 µm - 25/75	10 µm - 20/80	10 µm - 25/75
c/f related distribution	Double-spaced porphyric	Open porphyric	Open porphyric
Mineral fragments	Few (locally frequent) strongly weathered rounded claystones and subrounded sandstones	Few weakly weathered subangular claystones and sandstones	Few weakly weathered subangular claystones and sandstones
Fine material	Reddish-brown cloudy	Brown cloudy	Yellowish-brown cloudy
b-Fabric	Stipple speckled, yellowish-grey	Stipple speckled (locally striated), yellowish gray	Stipple speckled, yellowish-grey
Vegetal material	Very few plant residues (roots)	Very few plant residues (roots)	Very few plant residues (roots)
Pedofeatures	Very few rounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few microlaminated limpid-dusty clay infillings-crescents; very few matrix infillings	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; few matrix infillings

	F13/12 - 3Bt1	**F13/12 - 3Bt2**	**F13/13 - 2Bw1-2Bw2**
Microstructure	Vughy	Channel	Intergrain microaggregate
Aggregates	Dominant highly separated subangular blocky, very coarse sand size; frequent moderately separated granular, medium to fine sand size	Dominant weakly separated subangular blocky, gravel size	Frequent moderately separated granular, fine to very fine sand size
Porosity	Frequent star-shaped vughs, few channels	Few vughs, very few linear planes, very few channels	Frequent complex packing voids, few channels
c/f limit - c/f ratio	5 µm - 10/90	5 µm - 10/90	10 µm - 70/30
c/f related distribution	Open porphyric	Open porphyric	Single-spaced fine enaulic
Mineral fragments	Very few variably weathered subrounded claystones and sandstones	Few variably weathered rounded claystones and sandstones	Frequent weakly weathered subangular claystones locally subhorizontal
Fine material	Reddish-brown cloudy	Reddish-brown cloudy	Dark brown cloudy
b-Fabric	Stipple speckled (locally grano-porostriated), brown	Grano-porostriated, reddish-brown	Stipple speckled (locally granostriated), yellowish-brown
Vegetal material	Very few plant residues (roots)	-	Very few plant residues (roots)
Pedofeatures	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few nonlaminated typic or microlaminated dusty clay coatings	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few nonlaminated typic or microlaminated limpid and dusty clay coatings; very few fabric hypocoatings (compaction); few matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary

	F13/13 - 3Bw-3Bt	**FG13/15 - EB**	**FG13/15 - Bt**
Microstructure	Granular (subangular blocky in the l.p.)	Complex, bridged grain/subangular blocky	Channel
Aggregates	Dominant (very few in l.p.) moderately separated granular, very fine sand size; common (dominant in l.p.) weakly separated subangular blocky, gravel size	Dominant highly separated subangular blocky, gravel to medium sand size	Very dominant weakly separated subangular blocky, gravel to very coarse sand size
Porosity	Frequent star shaped vughs in the u.p., few channels (few linear planes in the l.p.)	Few channels, very few vughs	Few channels, very few linear planes
c/f limit - c/f ratio	5 µm - 35/65 (15/85 in the l.p.)	10 µm - 60/40	10 µm - 10/90
c/f related distribution	Double-spaced fine enaulic (open porphiric in the l.p.)	Concave chito-gefuric (locally close porphiric)	Open porphyric
Mineral fragments	Frequent (very few in the l.p.) moderately weathered rounded claystones	Frequent variably weathered subrounded claystones	Very few variably weathered rounded claystones
Fine material	Reddish-brown cloudy	Yellowish rown cloudy	Brown cloudy
b-Fabric	Grano-porostriated, reddish-brown	Stipple speckled (locally granostriated), yellowish brown	Stipple speckled and grano-porostriated, yellowish-brown
Vegetal material	-	Very few plant residues (roots)	Very few plant residues (roots) and charcoals
Pedofeatures	Very few rounded typic nodules of Fe-Mn with clear boundary; very few nonlaminated impure clay coatings; very few fabric hypocoatings (compaction)	Very few subrounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction); common matrix infillings; very few excrements	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few typic-crescent microlaminated impure clay coatings (locally coarse); very few fabric hypocoatings (reorientation)

	FG13/15 - BtCg	**FG13/18 - Bt1**	**FG13/18 - Bt2**
Microstructure	Channel	Channel	Channel
Aggregates	Very dominant weakly separated subangular blocky, gravel to very coarse sand size	Very dominant highly separated subangular blocky, gravel size	Very dominant weakly separated subangular blocky, gravel size
Porosity	Few channels, very few linear planes	Few linear planes, very few channels	Few linear planes, very few channels

c/f limit - c/f ratio	10 μm - 50/50	10 μm - 35/65	10 μm - 25/75
c/f related distribution	Close porphyric	Double-spaced porphyric	Open porphyric
Mineral fragments	Frequent variably weathered rounded claystones	Few variably weathered rounded claystones and sandstones	Few strongly weathered rounded claystones and sandstones
Fine material	Reddish-brown cloudy	Yellowish brown to light brown (striated) cloudy	Gray to brown (striated) cloudy
b-Fabric	Grano-porostriated, yellowish-brown	Striated (locally unistrial), yellowish- to reddish-brown	Striated (locally unistrial), yellowish- to reddish-brown
Vegetal material	Very few plant residues (roots) and charcoals	Very few plant residues (roots)	Very few plant residues (roots)
Pedofeatures	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few typic-crescent microlaminated limpid clay coatings (locally coarse); very few excrements	Very few rounded typic nodules of Fe-Mn with sharp-clear boundary; very few typic-crescent microlaminated limpid clay coatings; very few fabric hypocoatings (reorientation)	Very few rounded (locally aggregate) typic nodules of Fe-Mn with sharp-clear boundary; very few typic-crescent microlaminated limpid clay coatings; very few fabric hypocoatings (reorientation)
	FG13/18 - BtCg	**FG13/26 - 2Ab**	**FG13/26 - 3Bw2**
Microstructure	Channel	Complex, granular/subangular blocky	Complex, pellicular/intergrain microaggregate
Aggregates	Very dominant weakly separated subangular blocky, gravel size; locally dominant highly separated curved (slickensides) angular blocky, coarse to medium sand size	Dominant highly separated granular, very fine sand to silt size; common highly separated subangular blocky, coarse to medium sand size; secondary dominant moderately separated subangular blocky, gravel size	Frequent moderately separated crumb, very coarse to medium sand size; common moderately separated granular, medium to very fine sand size
Porosity	Few linear planes (locally curved), very few channels	few complex packing voids, few channels, few linear planes locally horizontal-vertical	Frequent complex packing voids, few star shaped vughs
c/f limit - c/f ratio	10 μm - 25/75	5 μm - 40/60	5 μm - 60/40
c/f related distribution	Open porphyric	Double-spaced enaulic	Double-spaced chito-enaulic
Mineral fragments	Few strongly weathered rounded claystones and sandstones	Few quartz grains; very few moderately weathered subrounded claystones and sandstones	Common quartz grains; very few moderately weathered subrounded claystones and sandstones
Fine material	reddish brown cloudy (with gray zones)	Reddish brown cloudy	Yellowish brown cloudy
b-Fabric	Stipple speckled, red (striated locally unistrial, gray to yellowish-brown in gray zones)	Stipple speckled, reddish-brown	Stipple speckled, brown
Vegetal material	-	Very few plant residues (roots)	-
Pedofeatures	Very few rounded (locally aggregate) typic nodules of Fe-Mn with sharp-clear boundary (absent in gray zones; few (very few in gray zones) typic-crescent microlaminated limpid clay coatings; very few fabric hypocoatings (reorientation)	Very few rounded alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)	Very few rounded alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary
	FG13/26 - 3BC	**FG14/19 - A**	**FG14/29 - A**
Microstructure	Pellicular	Granular	Intergrain microaggregate
Aggregates	-	Very dominant moderately-weakly separated granular, very fine sand to silt size	Common highly separated granular, very fine sand to silt size
Porosity	Frequent complex packing voids	Frequent complex packing voids, very few linear planes locally horizontal-vertical	Frequent complex packing voids, few channels
c/f limit - c/f ratio	5 μm - 75/25	10 μm - 25/75	10 μm - 75/25
c/f related distribution	Chito-gefuric	Double-spaced fine enaulic	Close fine enaulic
Mineral fragments	Dominant moderately weathered subangular sandstones; few quartz grains	Common quartz grains	Common quartz grains; common weakly weathered subangular sandstones
Fine material	Brownish gray cloudy	Yellowish brown speckled	Brown speckled
b-Fabric	Crystallitic, gray	Stipple speckled, grayish- to reddish-brown	Stipple speckled, grayish-brown
Vegetal material	-	Very few plant residues (roots) and charcoals	Very few plant residues (roots)
Pedofeatures	Very few rounded alteromorphic nodules of Fe-Mn with sharp-clear boundary	Very few subrounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few fabric hypocoatings (compaction)	Very few subrounded-irregular alteromorphic nodules of Fe-Mn with sharp boundary; very few excrement infillings
	FG14/29 - 4Ab-4Bw-5Ab	**FG14/36 - A**	**FG14/36 - 2Bt1-2Bt2**
Microstructure	Intergrain microaggregate	Intergrain microaggregate	Complex, vughy/channel (channel in the l.p.)
Aggregates	Frequent highly separated granular, very fine sand to silt size	Few highly separated granular, very fine sand to silt size, grouped in clusters; very few clayey pedorelicts, very coarse sand size	Very dominant weakly separated subangular blocky, gravel size
Porosity	Frequent complex packing voids, very few channels and planar voids locally horizontal-vertical	Dominant complex packing voids	Few channels and star shaped vughs, very few linear planes
c/f limit - c/f ratio	10 μm - 50/50	10 μm - 75/25	5 μm - 25/75 (10/90 in the l.p.)
c/f related distribution	Single-spaced fine enaulic	Fine close enaulic	Double-spaced porphyric (open porphyric in the l.p.)
Mineral fragments	Common quartz grains; very few weakly weathered subangular sandstones	Frequent weakly weathered subangular subhorizontal claystones and sandstones	Few weakly-moderately weathered rounded claystones
Fine material	Brown speckled	Brown speckled	Reddish-brown cloudy

b-Fabric	Stipple speckled, dark brown	Stipple speckled, dark brown	Stipple speckled and porostriated, reddish-brown (mozaic speckled and grano-porostriated, yellowish-brown in the l.p.)
Vegetal material	Very few plant residues (roots) and charcoals in the l.p.	Very few plant residues (roots)	Very few partially burned wood fragments
Pedofeatures	Very few subrounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp boundary; very few excrement infillings	Very few rounded typic nodules of Fe-Mn with sharp boundary; one fragmented impure clay infilling; very few depletion hypocoatings and matrix infillings	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few nonlaminated typic-crescent limpid-dusty clay coatings; very few fabric hypocoatings (reorientation); few matrix infillings

	FG14/36 - 2Bt3
Microstructure	Complex, subangular blocky/channel
Aggregates	Very dominant highly separated subangular blocky, gravel size
Porosity	Few channels, very few linear planes
c/f limit - c/f ratio	5 µm - 15/85
c/f related distribution	Open porphyric
Mineral fragments	Few moderately weathered subangular-subrounded claystones
Fine material	Reddish-brown (yellowish-brown in the l.p.) cloudy
b-Fabric	Striated and grano-porostriated, reddish-brown (mozaic speckled and grano-porostriated, yellowish-brown in the l.p.)
Vegetal material	Very few partially burned wood fragments
Pedofeatures	Very few rounded-irregular alteromorphic and typic nodules of Fe-Mn with sharp-clear boundary; very few microlaminated typic-crescent limpid-dusty clay coatings; very few fabric hypocoatings (reorientation); few matrix infillings