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Geoarchaeological study of a Neolithic soil from the site of Brentonico-Palù (TN)

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Abstract

In the latter decades, the use of geoarchaeological methods to better comprehend the dynamics of archaeological sites has increased, demonstrating to be an optimal tool for the understanding of past environments and settlements. The application of these techniques has been correlated to other disciplines which, with their contributions, enlarged the possibility of having a broader and more precise framework of the studied context. Together, these subjects lead to a higher possibility to reveal the secrets of past cultures through the analysis of soil chemical and physical changes, biological elements embedded in sediments, and their disposition considering both the local environment, and also a wider framework characterized by the surroundings.

In this work, geoarchaeology is applied on a site located at the centre of the town of Brentonico, located on a terrace comprised between the slopes of Mount Baldo and the valley of Adige River. The emergency excavation exposed a settlement dated from the end of the Mesolithic period until the first part of the Copper Age. In order to provide further information regarding this site, characterized by the presence of ceramic and hearths attributed to the Squared Mouth Pottery (SMP) culture, several analyses were conducted by the University of Padua. Through the use of micromorphology performed on thin sections, granulometries of sediments of the sequence, and radiocarbon dates it was in fact possible to reconstruct the evolution of the site and of the surrounding environment, and the chronology. The data elaborated from these analyses were compared with previous studies of similar sites in the same region, Trentino Alto-Adige, but also with other settlements found in the vicinities or in environments which share the same characteristics with Brentonico, both from the cultural as well as from the geomorphological standpoint.

The situation which appeared during the excavation, then confirmed by the analyses, showed the interesting presence of a thick dark A horizon, developed on substrate composed of reddish sediments. The whole sequence is placed over the remnants of glacial activities, probably dated to the Last Glacial Maximum.

The following five chapters are articulated as follow: first, a general overview of the geomorphological implant of the area under investigation is given, followed by an archaeological outline of the Neolithic period in Northern Italy, in order to better understand the context within the site. Finally, the first chapter ends with a brief introduction to the creation and development of soils, their pedogenesis and the characteristics noticed within the Po Plain, near the mountain ranges and within river valleys as described by other scholars. The second chapter opens with the definition and

location of materials collected on site, to then describe all the processes they underwent to before the actual analyses were performed. The methods applied to these samples followed specific protocols and were performed in collaboration with technicians of the University of Padua and other European laboratories. In the third chapter, resulting data are expressed in tables and graphics, with the exception of thin sections data which present a brief description, placed in Appendix A. It is in the fourth chapter that all the results are interpreted and explained, making comparisons and including theories and thoughts of other scholars.

In questi ultimi decenni è aumentato l'uso di metodi geoarcheologici per comprendere meglio le dinamiche di alcuni siti, dimostrandosi come uno strumento ottimale per la comprensione degli ambienti e degli insediamenti del passato. L'applicazione di queste tecniche è stata correlata ad altre discipline, che con i loro contributi hanno ampliato la possibilità di avere un quadro più ampio e preciso del contesto studiato. Insieme, questi metodi portano a una maggiore possibilità di rivelare i segreti delle culture passate attraverso l'analisi dei cambiamenti chimici e fisici del suolo, di elementi biologici incorporati nei sedimenti, e la loro disposizione considerando sia l'ambiente locale, oltre a un quadro più ampio caratterizzato dall'ambiente circostante.

In questa ricerca si applica l'uso della geoarcheologia a un sito situato al centro del paese di Brentonico, localizzato su una terrazza compresa tra le pendici del monte Baldo e la valle dell'Adige. Lo scavo di emergenza ha esposto un insediamento datato alla fine del periodo mesolitico, che ha continuato a vivere fino alla prima parte dell'età del Rame. Al fine di fornire ulteriori informazioni su questo sito, caratterizzato dalla presenza di ceramiche e focolari attribuiti alla cultura dei Vasi a Bocca Quadrata (VBQ), sono state effettuate diverse analisi da parte dell'Università degli Studi di Padova. Attraverso l'impiego di micromorfologia eseguita su sezioni sottili, granulometrie dei sedimenti della sequenza e datazioni al radiocarbonio è stato possibile ricostruire la cronologia del sito e dell'ambiente circostante. I dati elaborati da queste analisi sono stati confrontati con siti simili precedentemente studiati nella stessa regione, il Trentino Alto-Adige, ma anche con altri insediamenti trovati nelle vicinanze o in ambienti che condividono le stesse caratteristiche di Brentonico, sia dal punto di vista culturale che da quello geomorfologico.

La situazione che è emersa durante lo scavo, ma anche dopo le analisi, ha mostrato l'interessante presenza di un orizzonte A molto spesso e scuro, sviluppato su substrato composto da sedimenti rossastri. L'intera sequenza è collocata sopra i resti di attività glaciali, probabilmente datati all'Ultimo Massimo Glaciale.

I seguenti cinque capitoli sono articolati come segue: in primo luogo, viene fornita una panoramica generale dell'impianto geomorfologico della zona oggetto di indagine, seguita da un'introduzione archeologica del Neolitico nell'Italia settentrionale, per comprendere meglio il contesto del sito. Infine, il primo capitolo si conclude con una breve introduzione sulla creazione e lo sviluppo dei suoli, la loro pedogenesi e le caratteristiche osservate nella pianura Padana, nelle zone montane e nelle valli fluviali come descritto da altri studiosi. Il secondo capitolo si apre con la definizione e l'ubicazione dei materiali raccolti in loco, per poi descrivere tutti i processi a cui sono stati sottoposti prima che fossero effettuate le analisi vere e proprie. I metodi applicati a questi campioni hanno seguito protocolli specifici e sono stati eseguiti in collaborazione con tecnici del l'Università di Padova e di altri laboratori europei. Nel terzo capitolo, i dati risultanti sono espressi in tabelle e grafici, con l'eccezione dei dati delle sezioni sottili che vengono presentati in una breve descrizione, inserite nell'appendice A. È nel quarto capitolo che tutti i risultati vengono interpretati e spiegati, facendo confronti e includendo teorie e pensieri di altri studiosi.

1. Introduction

The use of geology and its tools, lexicon, and concepts has always been a part of archaeology, since its definition as a scientific matter. Nowadays, several different specializations of archaeology are connected to other sciences, such as physics, chemistry, and biology. However, geology and its sub-disciplines still represent an important help in the characterization of sites and in the study of their components. In fact, geoarchaeology provides important information and a deeper understanding of dynamics involving both natural processes and human actions, and the relationship between artefacts and ecofacts (Bassetti, 2004). The field of geoarchaeology expanded in the last years to be an integral part of the study in the field, and not only. Once all the detectable information on the site are acquired, records can be transported into laboratories to perform further analysis and give an explanation to phenomena happened in a given place at a given time. With time, new specializations were created and perfectioned from other subjects to fit the aims of archaeology: among these there is archaeological soil micromophology (i.e., «the microscopic study of soils and soil-like materials» (Macphail, Courty and Goldberg, 1990) which allows more detailed analysis, considering all the aspects that may determine and characterize the soil. Along with this analysis, it is possible to cite granulometries as an important tool for soil investigations, through which it is possible to understand several aspects (as for example the medium of transportation) that succeeded within the stratigraphy.

A geoarchaeological approach to the study of a site is important because it allows us to identify and determine several events, whether these were the result of human actions or of natural processes, and help in the understanding of a site birth, development, and abandonment. It allows to comprehend the choices of locations for settlements, how humans lived and how they managed the organization of spaces. At the same time, geoarchaeology provides information on the state of the environment at specific times, the climate and variations in soil characteristics. To summarize, geoarchaeology is a key tool in order to have a broad knowledge of the features within a site, concerning both human actions and natural events.

The following study concerns the analysis of a site located at the centre of the city of Brentonico (Trento), discovered during construction works. The nature of circumstances which led to the finding of the site determined a specific typology of excavation, that was a rescue or emergency dig. The emergency intervention can be related to the necessity of safeguard of cultural heritage, and it is also evidenced by the velocity with which the excavation was conducted and the reasons why undiscovered archaeological records and the site itself cannot be further investigated. During the short

and intense period of excavation, the work was delegated from the Superintendence of Trento province (Umst: Soprintendenza per i Beni e le Attività Culturali) – under the supervision of Dr. Chiara Conci - to the company Ar. Tech. During the years 2023/2024, archaeologists carried out the rescue excavation, during which sampling procedures were put in practice.

The samples on which analysis were conducted regarded micromorphological thin sections, granulometries and radiocarbon dating. In total sixteen sediment blocks for thin sections and fourteen bulk samples for granulometries were collected, as well as eleven charcoal fragments to date. Charcoals and wood fragments were, at first, analysed and identified in their species by F. Breglia of the University of Padua, and then were sent to two different laboratories (University of Groningen and University of Aarhus) to be dated. As far as the thin sections are concern, the blocks were worked and prepared by technician F. Sartor in the laboratory of micromorphology of the University of Padua and then observed at the microscope. The preparation for granulometric analysis was carried out by technician S. Cattò in the laboratory of sedimentology of the Department of Geosciences.

In a preliminary overview of the site, and thanks to the excavation data given by the company who carried out the work, it was already possible to estimate the life period of the site, then confirmed by radiocarbon dating. Archaeological remains demonstrated the presence of a settlement, or at least of human activities, already from the Mesolithic to be then more extensively frequented during the Neolithic period. The last evidence of human presence as inhabitants of the site can be identified in the first part of Copper Age.

Particularly interesting, already during observations in the field, was the presence of a very expressed A horizon on which the Neolithic site developed. This appeared, as it will be further articulated, in agreement with the discoveries of Neolithic sites effectuated in other areas of Northern Italy.

Considering these preliminary information, the aims of this research include the establishment of a chronology for the settlement, but also of the surrounding environment, using geoarchaeological techniques and analysis. The focus is placed on the investigation of sediments composing the sequence of the site and the ones determined as prior to its foundation. The site of Brentonico presents an interesting geoarchaeological set, in which the whole archaeological sequence appears as “digested” in a well-expressed topsoil (A horizon). Attention was paid to the surroundings as well, considering the presence of natural features which may have conditioned the site with their actions.

1.1 Geomorphological Framework

The area considered in this study is located in the Northern part of Italy, in the Trentino Alto-Adige region and it is comprised between different morphological features. Two main features determined the landscape of the Southern part of Trentino region and contributed to all the modifications that occurred in the area: the Mount Baldo range and the Adige River. Both of them will be further examined, briefly analysing their origin, morphological aspects and the importance for the development of the Plateau of Brentonico.

The Mount Baldo is a mountain range 38 km long and between 10 and 12 km wide (Brentari, 1893). It is delimited to the East by the Valle dell'Adige and Val Lagarina, while towards the West and South by the Lake of Garda (Brocada, 2022). The range extends in NNE-SSW direction, and it is articulated in a principal ridge, plateaux, and terraces. Its flanks present cuts made by a series of glacial and torrential erosions connected to the valley floor, determining landslides and karstic phenomena (Chelidonio, 2004). The Mount Baldo can be divided in two longitudinal sectors: a Western sector characterised by a fold system, an anticline and syncline, and an Eastern sector composed of weakly inclined blocks (monoclines) (Antolini and Fogelgesang, 1979). At the same time, the range can also be subdivided into two more sectors considering position and configuration: it is possible to distinguish a "Baldo Trentino" towards the North and a "Baldo Veronese" toward South separated by Bocca di Navene. The present work considers the area of Baldo Trentino, which presents a curved central mass covered by clumps. At the same time the focus is placed on the Eastern side of the Mount Baldo, an area in which the surfaces are weakly inclined proceeding toward East where they encounter the fertile basin of the plateaux of Brentonico and Prada (Brentari, 1893). The Eastern side of this mountain range represented a perfect area in which human groups settled and created productive sites, already during Prehistoric times (Bassetti and Borsato, 2007).

The different features present in the area dominated by Mount Baldo are determined by the fact that this latter consists of a complex combination of different units, as every mountains consist of morphotectonic units, structures determined by their composition, lithological successions, and different types of deformations (Turri and Passerini, 1993). The units that compose Mount Baldo range are different and were subjected to many phenomena which modified its shape and arrangement. The origins of this mountain range were set around 200 and 100 Million years ago, when the movement of continental plates – the paleo-African and the paleo-European – established slow subsidence movements of coastal plains. This process led to the deposition of huge mud sediments, then lithified in about 1000 m of dolomitic rocks. In the area of Mount Baldo, at this time,

the sedimentary strata were still located at a shallow depth, but with a swiftly subsidence of the Plateau of Trento – about 180-135 Million years ago – a new sedimentation of whitish calcareous sediments, enriched with silica from the dissolution of micro-organisms, occurred. During the Upper Cretaceous, the layers under the Ocean floor began to compress until they experienced a subsidence phenomenon too. The compression led to the deformation of sediments, folding and cracking them, determining an overlapping of the older rocks over the recent ones. Other several processes of this kind succeeded during the millennia, with a particular importance given to the environmental conditions determined by glacial cycles of the last 2 Millions of years (Chelidonio, 2004). In fact, particularly the Eastern sector of Mount Baldo was shaped and modified by a combination of glacial actions and neotectonics actions: the first one progressively deepened the valley floor, while the second determined an uplifting of 400-600 m thanks to orogenetic impulses. The morphologies were modified also by cryoclastic, snow-related, and karstic phenomena (Chelidonio, 2004). Ultimately, in the Mount Baldo range there are many different forms of erosion still visible today, such as niches of landslide caused by gravity, valleys originated by water courses, and again gullies shaped by glaciers action. But at the same time, there are evidence of depositional forms too, as debris and fluvial deposits, glacial and periglacial deposits (Turri and Passerini, 1993).

Mount Baldo presents a set of rocks, although with a variety of lithotypes, constituted by dolomites and calcareous dolomites, yellow-pink to white-grey in colour, generally without microfossils. Moreover, it is possible to find breccias with oxidized products and sediments laminated with algae and crystalline dolomites (Turri and Passerini, 1993). There is also the presence of volcanic rocks derived from the Eocene underwater volcanic activity. This was possible thanks to the perforation of ancient rocks, and the consequent formation of tuffs and basalts, which overlapped the already existing calcareous platforms. In the Trentino region, rocks related to those effusive actions are limited to some areas: the Mount Baldo range and the villages at its slopes, as for example Brentonico itself. Another limited feature in Trentino region, localized in the southernmost part as Mount Baldo, are calcareous sedimentary formations of marine origin (Avanzini, 2006).

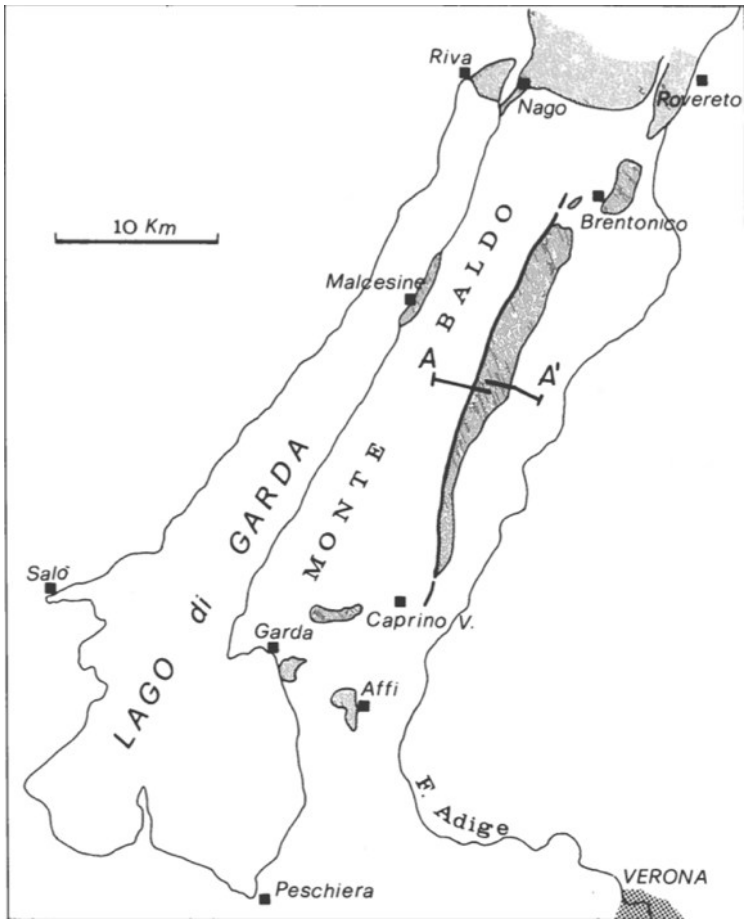

Figure 1 Tertiary outcrops localization (grey) on the Eastern side of Garda Lake (Bosellini et al., 1988).

As far as it is considered the botanical variety, the area dominated by the influence of Mount Baldo presents an exceptional diversity of vegetation, with about 1.655 entities. This assortment is mainly due to the presence of many microclimates and geographic-environmental characteristics. In fact, the climate of the mountain range suffers the influence of the close Garda Lake basin, which mitigates the climate thanks to the heat release accumulated in waters and winds. Also, the NNE-SSW orientation of the range allows the presence of humid currents in the slopes constraining precipitations. Finally, the other phenomena influencing the climate are the altitude range and the slopes exposition. Generally, on Mount Baldo there are typical mountainous climate conditions, rigid temperatures in winter and moderate temperatures in summer, other than abundant snow precipitations during winter months and temperature range present all over the year (Ferrari, 2013). More specifically, considering the Eastern side of Mount Baldo, a series of different zones are present, which from bottom to top correspond to: Mediterranean belt, sub-mountain belt, sub-Alpine belt, and Alpine belt (Brocada, 2022).

The second feature that represents an important element for the understanding of the geomorphological framework of Brentonico area is the river Adige and its Valley. The Adige river is

one of the main rivers in Italy, especially concerning the Northern Mediterranean, with its length of 410 km and a drainage basin of 12.16 km². It presents the features of a mountain stream, running with a W-E direction until the Adige floor valley, where it expands acquiring the characteristics of a narrow and stretched out alluvial plain. From Bolzano up to Chiusa di Ceraino, the Adige River appears as a strong incision with NNE-SSW direction of the flow (Angelucci, 2016). The River is placed at about 1.500 m a.s.l., and according to the Rust classification it is ordered as a meandering river.

Scholars affirm that the origin of fluvial valleys present in the area, including the Adige valley, is set starting from the Late-Tertiary period. Particularly, it is popular the hypothesis of a main phase, in the Upper Miocene, during which the major incision activity took place (Bassetti and Borsato, 2007). However, already 70 Million years ago, in the Upper Cretaceous, a tectonic activity started and contributed to the deformation and displacement of some sectors in the Alps. This event influenced the formation of rivers, considering that along tectonic lines – in this specific case the so-called "Linea delle Giudicarie" which was already weakened – the hydrographic network set, and it permitted to reach the sea in the shortest possible time (Angelucci, 2016). With regard to the Adige Valley, its depth, the typical "V" shape and the characteristic canyons with different profundities are the result of an intensive erosive action. The starting of this event needs to be considered as related to the "Messinian Crisis", during which the Strait of Gibraltar closed consequently to tectonic movements that isolated the Mediterranean Sea from the Atlantic Ocean. The separation between the two water reservoirs led to the lowering of Mediterranean and to the draining of other watercourses. The result was represented by the incision of the course itself, determining an instable and erosive period that stopped 5.3 Million years ago (Angelucci, 2016). In this period, the Adige River flowed in the "Valle dei Laghi" toward the basin now occupied by the Lake of Garda. Then it continued downstream in the lower Sarca Valley, through Loppio Valley and to San Giovanni Pass. Only after the Late Glacial, the Adige River started to occupy the current course (Avanzini, 2006). During the Quaternary, numerous climatic variations occurred, determining physical and environmental changes. Those variations were determined by the alternation of glacial and interglacial periods. During glacial periods, glaciers expanded and during the interglacial periods the higher temperatures led to a glacier retreat. In particular, 25.000 years ago the ALGM (Alpine Last Glacial Maximum) occurred, and a huge glacial mass accumulated in the Adige's valley. This mass underwent to transfluence actions, and two different glacier branches appeared: one of them moved toward West, along the nowadays Sarca Valley, the other one moved to East in the Adige Valley. The glacier placed in the Adige Valley presented a volume and a thickness inferior with respect to the Garda's glacier, and the retreatment of those glaciers is set between 17.000 and 11.500 years ago. In this period, also called Late Glacial, the melting and retreat of glaciers led to a mobilization of huge water quantities, with a consequent

stream and fluvial activities in the main and lateral valleys and in the Po Plain. Many other effects hit the Adige Valley, for example valley slopes lost support, and the absence of soils and vegetation covers allowed erosion, transportation and sedimentation of alluvial debris within the valleys (Angelucci, 2016).

Figure 2 Basin of Adige River and its hydrographic network (Modified from Turri & Ruffio, 1992).

Furthermore, the retreat of glaciers showed a series of streams within the calcareous rocks, covered by debris deposits, which flooded due to superficial waters that eroded the valley floors creating new riverbeds (Avanzini, 2006). Among the deposits found in the Adige's valley, it is

possible to ascribe a sequence of lacustrine silts to the Late Glacial. These are/were covered by gravel floods and floodplain silts dated to the Holocene. Only later on the vegetation, including forest covers, reconquered the valley and slopes up to 2.000 m a.s.l. (Bassetti and Borsato, 2007). Finally, with this stasis period it was possible to set the origin of river terraces, particularly, the ones present in Val Lagarina set their conclusive phase between 9.000 and 8.000 years ago. The stability seemed to end in the III Millennium BCE, followed by a sedimentary accumulation in the Adige and Sarca's valleys (Angelucci, 2016). Those gravely depositions, added to Holocene erosive events, determined important geomorphological variations in the whole territory (Bassetti and Borsato, 2007).

Simultaneously with the advance of vegetation, also biological communities and humans recolonized the area. Firstly, already during the Late Glacial groups of Epigravettian hunter-gathers arrived in the Alpine valleys and plateaux. Then, between the Pre-Boreal and the Boreal period, Mesolithic hunter-gathers groups extended their land-living over the majority of Adige basin and its surroundings (Angelucci, 2016). According to Broglio and Lanzingher (1996), already during the Older Dryas some settlements were present in pedo-mountainous and floor valley areas. While, specifically regarding the catchment basin of the Adige River, human settlements began to appear already in the 16.000 cal. B.C., using rock shelters at the margins of the valley floor (Fuganti et al., 2001). The human presence represented an important aspect for the following changes and developments that interested the Adige Valley. In fact, anthropic factors contributed to depositional, erosional and transport processes affecting the environment (Angelucci, 2016).

The village of Brentonico (Trento province) was built on a plateau formed by an anticline-syncline system, characterized by different and complex forms which gave life to a progression of fluvio-glacial terraces (Brocada, 2022). These terraces can be interpreted as the accumulation of earth from ancient landslides, dated to the Miocene this accretion was then partially covered by moraines, present in this sector as saved by erosive phenomena during the Quaternary (Antolini and Fogelgesang, 1979). The sediments on which Brentonico was built are very unstable, as they are composed by gravels and alluvial debris coming from Pleistocene deposits. In fact, the fluvio-glacial materials that compose the Plateau of Brentonico are poorly permeable, so that a marshy depression was able to form at the centre of the plateau (Turri and Passerini, 1993), where nowadays is present the "Palù" public park. The valley, adjacent to the plateau of Brentonico, corresponds to an excavated depression next to Val d'Adige, called Val Lagarina formed as consequence of regressive erosion processes, that is to say a bottom to top erosion, dated after the Ice Age. The erosion firstly deepened the Val Sorne trench and then, proceeding to the top, it isolated terraces and plateaux which resulted in steps-like features still visible in the surroundings (Turri and Passerini, 1993).

In order to better understand the geomorphology and geology of this area, it is necessary to use the Italian Geological Map (Carta Geologica d'Italia), with a scale of 1:50.000, and its illustrative notes. Specifically, Brentonico falls within the map number 080, Riva del Garda (see Appendix C), in its Eastern lower corner. Sheet 080 represents the central sector of the Southern Alps, originated from the compressive structural inversion of the post-collisional evolution of the Alps. The Map shows how the village of Brentonico developed over the Garda Synthem (SGD), which comprehends glacial and fluvioglacial deposits dating back to the Last Glacial Maximum (LGM) and therefore related to the Upper Pleistocene. Within this synthem, two different subsyntem were identified, as they better specify the singular Late Glacial phases of the LGM: the Malè Subsynthem (SGD1) and the Bondo Subsynthem (SGD2). The deposits related to the LGM, present within the Garda Synthem, are referred to two big basins of alimentation: one in the Central sector, the Rendena-Sarca, and one in the Central-Eastern sector, the Atesian, both converging in the depression of Riva del Garda. Typical features present in the SGD area are accommodation till, diamictites with a silty matrix very much consolidated, and grey in colour. Ablation till, a structureless diamictite densified with polygenic heteromers in a clastic support, or more frequently in a sandy-loam matrix, red, light brown or grey in colour, is also present. Finally, deposits from glacial contact, characterized by different and heterogeneous facies within the Synthem of Garda from which it derives a complex subdivision and textural representation can be found (Castellarin et al., 2005).

However, the territory of Brentonico is also characterized by basic volcanic rock outcrops, which may determine erosive events. Those actions, when happen, are always rotational slides evolving in slow debris flows or mudflows, a phenomenon that presents a seasonal evolution, conditioned by meteoric precipitations. In the geological map, those basic volcanic rocks are represented under the acronym VUB, also called Val Lagarina Basalt. The whole area, in fact, was subjected to intense submerged volcanic activities during the Lower Eocene, producing accumulations of ialoclistites. Then, also voluminous explosion breccias, lava flows, and basaltic dikes were created. Volcanic rocks and the principal eruptive features are all localized in the further Eastern part of the Sheet 080, with rare intercalations of Chiusole Formation, micritic and glauconitic limestones with radiolarians and planktonic foraminifera, found in minor thickness in the area of Brentonico (Castellarin et al., 2005).

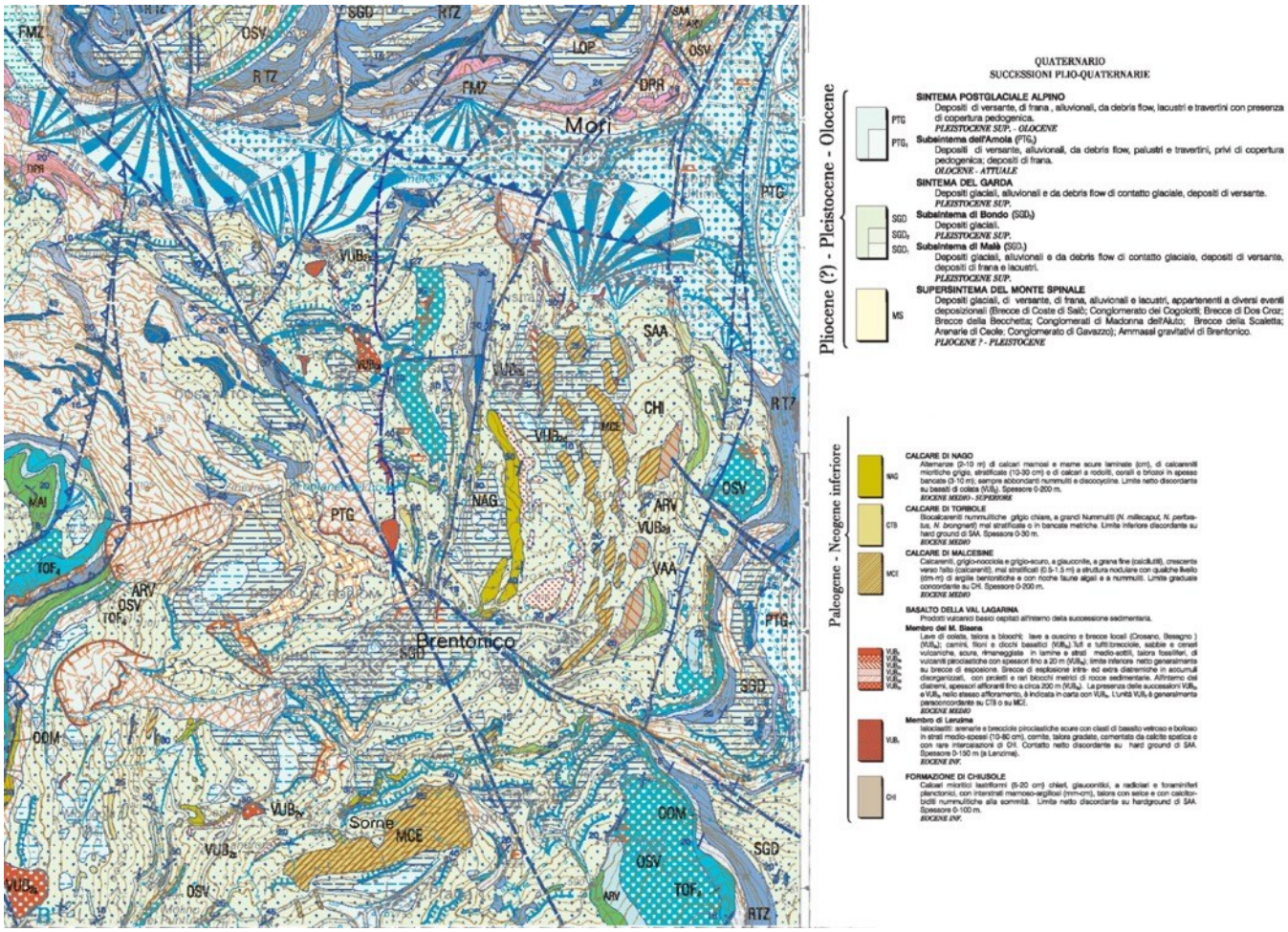

Figure 3 Italian Geological Map representing Brentonico and its surroundings, with the main geological formations. (Modified from Castellarin et al., 2005).

1.2 Archaeological Framework

Once the geomorphological framework of the site of Brentonico is established, it is necessary to identify the chronology of the settlement in order to be able to recognise the possible dynamics in which the study is contextualized. The archaeological record and the radiocarbon data make it possible to assert the site of Brentonico in a chronological range that spans from the Mesolithic up to the beginning of the Copper Age. This study focuses on the Neolithic, particularly taking in consideration the period of origin, development and decay of the Square-Mouthed Pottery culture in Northern Italy.

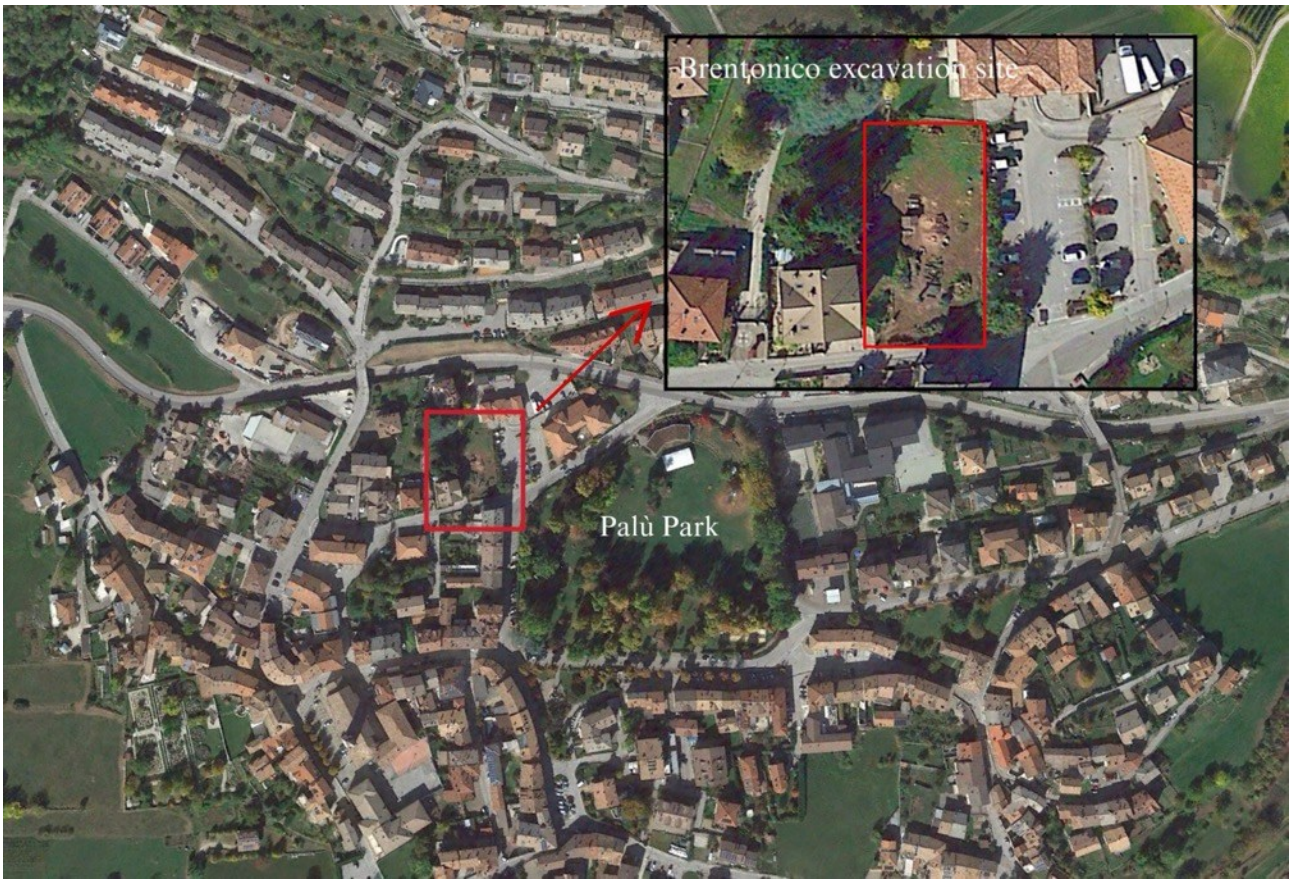

Figure 4 Location of Brentonico's site (an eleaboration from Google Earth).

As it was already anticipated in the previous paragraph, it is attested that the margins of the pre-Alpine area were already inhabited by Epigravettians groups. Nevertheless, at the end of Bölling period (ca. 12.400-12.300 ^{14}C cal. BCE) the anthropic colonization appeared more consistent, especially with seasonal camp at medium-low elevations or in valley floors. The documentation about these sites is very limited, due to all post-depositional processes which altered the majority of anthropic evidence, and this led to a scarce knowledge about the first settlements in the sub-Alpine region (Bertola et al. 2005). Particularly important are the climatic changes that occurred between the Boreal and Atlantic period, around 8.000 ^{14}C cal BCE. In fact, the Mediterranean area experienced

the Hypsithermal period, also referred as Holocene Climatic Optimum, during which temperatures and humidity raised and the tree cover expanded up to 1.900-2.300 m a.s.l. The importance of this reconquer of nature is evidenced by the biodiversity which allowed human productivity and therefore the settlement of human groups. The water element is crucial as well and it is proved by the percentage (70%) of sites close to plateaus, fluvial confluences, valley floors and where perennial springs or natural ponds are found (Franco, 2011).

The term "Neolithic" was introduced by John Lubbock, in 1865, to identify the period after the Palaeolithic characterized by the introduction of polished stones and ceramic. More recently, the real innovation that defined this new period was identified in the productive economy, in agriculture and animal husbandry. Those three elements not only defined and introduced new technological innovations, but at the same time they led to social and ideological changes too.

Generally speaking, some of the changes that the Neolithic brought are represented by the deforestation of areas used for agriculture, through slash-and-burn actions, the use of sickles (with wooden or bone shaft and flint blade) for harvesting, and the use of stone mills to grind cereals. The most common cultivated plants were some cereals, as barley (*Hordeum disticum* and *vulgare*), spelt (*Tricticum dicoccum*) and einkorn wheat (*Tricticum monococcum*), but there were also legumes as lentil (*Lens culinaris*), pea (*Pisum sativum*) and other plants as linen (*Linum usitatissimum*) and poppy (*Papaver smoniferus*). Among the animals that were domesticated there were dogs, sheep and goats, pigs, and bovines. However, hunting and fishing were still present and considered as an important integrative resource, with a different prominence depending on the area considered. Almost everywhere the ceramic was present and largely diffused, while the lithic industry mainly focused on tools chipped and polished (Cocchi Genick, 2009).

Talking about the first Neolithic in Northern Italy appears difficult, due to the fragmentation within such a limited area. Within this area, the number of different environments is wide, and it comprises the low Lombard, Venetian and Friulan Plain, the pre-Alpine and Apennine hills, big lakes as Garda Lake, Como Lake and Iseo Lake, and mountainous environments from the Alpine range (Cavulli, 2020).

The first step into the comprehension of the Neolithization process of the area under investigation, the Trentino region, presents the necessity of a broader look outside of this region. In fact, it is necessary to take in consideration all the different influences coming from other parts of Northern Italy, and more. First of all, the Impressed Ware culture of Liguria (dated about 5,790-5,660 cal. BCE) and the Adriatic Impressed Ware culture, but also contributes from North-Western Balkan and Central Europe led to confluences and interconnections with pre-existing local Mesolithic groups.

This theory regarding an acculturation phenomenon is testified by the economic systems of the first Neolithic settlements, which were still particularly oriented toward hunting, with scarce evidence of agricultural and husbandry practices (Pessina and Tiné, 2008). However, recent studies preferred to enhance the prematurity of agricultural activities achieved by Neolithic groups, rather than the manifestation of a Mesolithic tradition. Therefore, it is possible to say that the Padano-Alpine area suffered the Neolithization process as a composition of different circumstances, and not only based on the diffusion and acculturation paradigm (Pessina and Tiné, 2008).

Parallel to more recent phases of the Ligurian and Adriatic Impressed Ware culture, many different societies developed in the Italian Northern regions. The most important for the Trentino Alto-Adige region will be now briefly described in their characteristics. Starting from Fiorano culture, it appeared in Emilia-Romagna, Veneto and Northern Tuscany between 5.500 and 4.800 cal. BCE. This cultural group has to be considered important for the presence of its peculiar elements (such as rhomboids and gravers of Ripabianca) in other groups. Then, the Vhò group appeared in Western Emilia, Lombardy and South-Eastern Piedmont and developed between the end of VI and the beginning of V Millennium cal. BCE. It presented some features of the Fiorano group, and it was characterized by the presence of the Alpine flint, from Jurassic-Cretaceous formations of the Veronese area. Later on, it was attested the presence of culture groups from Friuli Plain, which expanded their settlements up to the Tagliamento River morainic amphitheatre and presented a chronological period that spans from 5.500 to 4.700 cal. BCE, partially overlapping Fiorano culture and the first phase of SMP culture. Finally, closer to the Neolithization process, it appeared the so-called Gaban group. Especially in Trentino region, emerging in rock shelters (already visited by Mesolithic people) and rarely in open-air sites or on plateaux along the Adige Valley (Cocchi Genick, 2009; Pessina and Tiné, 2008). Particularly interesting for this study is the Gaban culture, which developed later than the other Northern groups, but it is well attested in many sites of the Trentino Alto-Adige region. It is shown that the majority of Gaban's sites are rock shelters, with the exception of one open-air site, La Vela, in Trento. While in the Alto-Adige part of the region (Valle dell'Isarco), open-air sites along plateaux at 700-850 m a.s.l. were the most common ones. The economy present in the shelters was still characterised by a Mesolithic style of hunting and gathering, whereas in the open-air sites it was already present a productive economy based on legumes and cereals cultivations and the husbandry of sheep. Scholars believe that in this area, along with other communities present in other Northern regions, the origin of agriculture can be dated between 5.520 and 5.340 cal. BCE, therefore in a later moment with respect to the groups settled in the Po Plain or in Liguria (Cocchi Genick, 2009).

Moving to the craftmanship production, there are evident connections between the Gaban group and Vhò, Isolino and Fiorano groups, thanks to lithic and ceramic elements. In fact, among vessels shapes it is possible to find «vases with tall or short neck and with a foot, earthenware pots, keel-based jugs, and bowls». Typically with decorations made of big triangles filled in with oblique lines, zig zag lines, with a reticule pattern or music notes patterns, all produced through incisions, scratches, impression and plastic techniques. Regarding the lithic production, this group showed typical features of the first Neolithic in the Po Plain, as Ripabianca burins, and traditional Mesolithic elements, such as bone and horn trowels and harpoon, other than shell ornaments (Cocchi Genick, 2009).

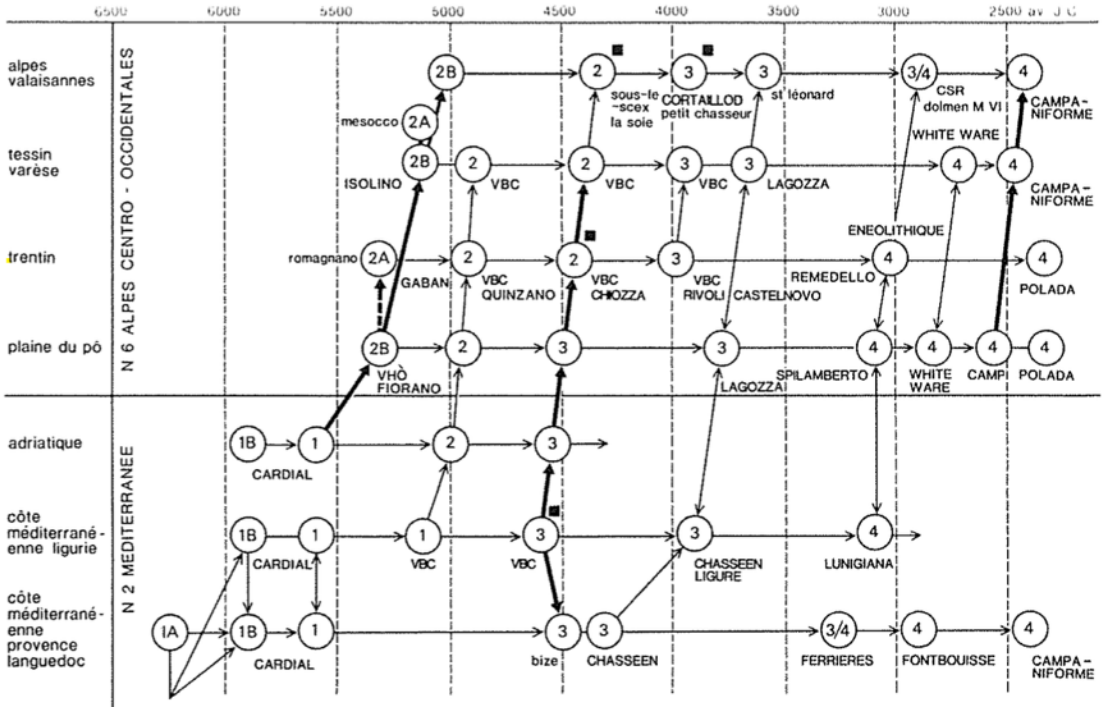

Figure 5 Spatio-temporal structure of Northern Italy neolithization (Gallay, 1990).

At the end of the VI Millennium cal. BCE the territory of Northern Italy, including Trentino Alto-Adige region, presented a varied situation in which different communities and cultures lived close one to another. Their relationship is evident in the presence of peculiar manufactures far from their place of origin, indicating not only "intercultural exchanges" but also "infracultural relations" (Ferrari, 2011). From this apparent disaggregated situation, there is a transition toward a single culture: the Square-Mouthed Pottery culture (Vasi a Bocca Quadrata, VBQ, in Italian). The name of this culture came from the peculiar mouth of the vascular production, and it originated at the end of the VI Millennium cal. BCE developing during all the whole V Millennium cal. BCE. In this period, the SMP culture evolved its features determining an internal subdivision in three moments: Lawrence Barfield, in the 1960s, proposed a chrono-cultural division based on already known sites, with an "ancient phase" based on Finale-Quinzano, a "middle phase" from Rivoli-Chiozza and a "recent phase" or Rivoli-Castelnuovo. More recently, Bernardo Bagolini and Paolo Biagi determined a new

subdivision based on three ceramic styles, SMP I or linear-geometric style (end of VI Millennium until the first half of the V Millennium cal. BCE) , SMP II or meandering-spiral style (4.600-4.200 cal. BCE), and SMP III or engraving and imprinted style (4.500-4.000 cal. BCE) (Pessina and Tiné, 2008). Briefly, the three phases of SMP proposed by Bagolini and Biagi will be described, with a particular attention to the Trentino and Adige Valley area. The SMP I spread in those territories already inhabited by Fiorano groups and in Western territories, from Liguria region, through Veneto, Lombardy, Trentino Alto-Adige and Emilia-Romagna. Specifically regarding the Adige Valley, this culture occupied sites placed on debris and alluvial fans, plateaux close to meanders of the Adige River, but also in rock shelters (Mottes, 2021). Clearly, this first manifestation presented different features linked to the previous culture within a territory, however, the "cosmopolitan" traits can be identified as a «semiotic convergence phenomenon», especially where there are not evident contact points (Ferrari, 2021). Typic of this period were vessels with a quadrilobate mouth, applied on variegate typologies and with a scratched style of decoration representing bands filled in with horizontal, oblique or reticulate lines. The lithic industry, although still connected to First Neolithic traditions, was now characterized by foliated cusps. A stability of the Square-Mouthed Pottery culture can be identified along with a technological, ideological transformation, together with the confirmation of a productive economy. This appeared to happen at the end of the SMP I style, when the meandering-spiral phase begun around the second quarter of the V Millennium cal. BCE (Mottes, 2021). Within the SMP II period, decorations were made through scratched techniques, incisions and excision, representing spirals, meanders and garlands. New vessel shapes appeared (decorated flared rim bowls and covers) while already seen shapes reduced or disappeared (necked and on foot vases). This new phase, however, shared with the previous one batter, shapes, syntax, and decorative techniques. In Trentino Alto-Adige, almost all the shelters still inhabited during the SMP I were abandoned, open-air sites were preferred as it is shown by the site of La Vela which reached its maximum occupational expansion. Almost contemporary to the SMP II, there was the development of the engraving and imprinted style probably as a consequence of trans-Alpine influence. This was attested in the North-Eastern area and in few sites of Eastern Lombardy and Emilia. The impressed or engraved designs presented zig zag, fish-bone and filled in triangle patterns, applied on convex truncated cone bowls, earthenware pots and squared-mouths with four spouts bowls. It is important to remember that during this phase, the majority of settlements were built on steep morphological culminations, probably for defensive purposes (Cocchi Genick, 2009). During the firsts centuries of the IV Millennium cal. BCE, the Square-Mouthed Pottery culture seemed to lose its «power unifying symbol», expressed by the rarefaction of typical SMP elements, the decline of qualitative and technological aspects of the ceramic industry, and impoverishment of terracotta vessels, but also

evident in elements typical of other cultures coming from North-Alpes or West, as the Chassey-Lagozza culture (Mottes, 2021).

Specifically regarding the case of Brentonico, the excavation brought to evidence a chronological sequence which can be subdivided in ten phases. The sequence presented natural layers intercalated by anthropic units, evidenced by traces of frequentations of the site. The oldest evidence is characterized by the "natural phase", the substratum over which the whole site developed: this includes three stratigraphic units or unità stratigrafiche (hereafter, US) (US 6, 7 and 8) characterized by a brown-reddish colour evident already in the field, with gravels and pebbles, and visible only in section. Successively, the second phase (US 5) presents a weakly anthropized soil identifiable from the pedogenesis active on the layer and the presence of rare charcoal fragments, and lithic industry. More evidence of frequentation and human actions were present in the third phase, where structures and hearths remnants were found. Here, many postholes and cuts probably indicating pits (ex. USS -344, 312) were alternated to lens of charcoal fragments and burnt soil fragments (ex. US 345), embedded in a brown-reddish soil characterized by gravels (ex. US 334). A more intense frequentation is represented in the fourth phase, where the found anthropic layers incremented as well as the amount of lithics and charcoal fibres (some of which were sampled, ex. US 321). Particularly interesting was a preparatory layer composed of gravels, pebbles and with lithic industry (US 302). Finally, the fifth phase was identified for the presence of settlement residues: among these there were a hearth used multiple times, postholes and sewers. This part of the sequence was recognized as of Lower Neolithic thanks to radiocarbon dating and ceramic material. Particular attention must be given to the hearth, which showed evidence of multiple uses and renovations: the first work surface (US 99) relies over a foundation cut (US -128) and presented charcoal lenses. The successive remaking of the structures showed an alternation of preparatory cuts with charcoals, burnt soil fragments and pebbles (ex. USS 268, 269, -127, 252, 251, 250). The settlement remnants attributed to the SMP culture were identified in the sixth phase, which seemed to start with the stop in the use of the hearth and its consequent abandonment. The characteristic soil (ex. USS 42, 43, 148) presented a silty clayish texture, brown to dark greyish in colour with rare gravels and both natural and anthropic inclusions (ceramic and lithic fragments). The main discoveries were postholes with more or less the same type of infill, characterized by ceramics, elements of the lithic industry and worked cherts. Moving up along the stratigraphy, the sixth phase ended with a series of pebble structures, some of these represented reclamations (ex. US 9) characterized by gravel, charcoals, burnt bones, ceramics and lithics, determining a related accumulation of the removed sediments (US 21). At the same level in the stratigraphy other pebble structures (ex. USS 16, 10) were organized by placing the elements

both horizontally (flat) and vertically (on edge). The seventh phase represented a soil developed after the abandonment of the site: the last evidence of SMP culture were present in the US 4, where ceramics, lithic fragments, charcoals and gravels were found in a very dark (almost black) brown-greyish soil. To conclude the life of this settlement, the eight phase presented a colluvium (US 3), i.e., slope materials (Leopold and Völkel, 2007). The last two following phases (the ninth and the tenth) represented modern fills and the contemporary phase (USS 2 and 1).

Figure 7 Squared-Mouthed Vase with incised and impressed decorations (Mottes, 2021).

Figure 6 Squared-Mouthed Vase with scratched technique decorations (Mottes, 2021).

The excavation of the site of Brentonico, and the preliminary data, allowed the identification of features also present in other sites located in the Trentino Alto-Adige and Veneto regions. To better contextualize Brentonico's site, a brief description of three other archaeological settlements will be present as following.

First, here it is the rock shelter of Riparo Gaban, located in the locality of Piazzina di Martigiano, about 45 km from Brentonico, on the left of the Adige River. This site, extensively excavated since 1970, is characterized by ceramic materials typical of the Gaban group, and it was probably used as a *habitat bergerie* (for the husbandry of ovicaprids). Micromorphological analysis showed the presence of *fumiers*, with an ongoing post-depositional transformation, indicating a periodic pastoral attendance within the shelter. Regarding the ceramic culture, it was attested a huge influence, on the SMP and first Neolithic elements, of features typical of the Po Plain (Mottes, 2021).
Moving to open-air sites, the site La Vela in Trento is located on an alluvial fan of the Adige Valley and its stratigraphy presents the longest settlement chronology for the Northern Italy, from Mesolithic

period up to Medieval times. Of particular interest, concerning the similarities with Brentonico, are the phases of SMP II and SMP III dated and documented through radiocarbon analysis and the investigation of ceramic fragments (Conci and Ziggiotti, 2021). Although La Vela is one of the most studied sites in Trentino regarding the Neolithic, it is not the only one: other examples can be found in the site of Covelo (Degasperi et al., 2006), the rock shelter of Ala Le Corone (Nicolis et al., 2007), and again the settlement of via Brione in Riva del Garda (Mottes and Degasperi, 2014).

Important sites that can be compared with Brentonico can also be found in Veneto region, in fact several examples of mountain settlements are present on the Lessini Mountains. One of the most important is the site of Lugo di Grezzana (VR), where analysis showed that already in the first phase abundant flint fragments and Fiorano Culture elements were present, while in the successive phases more different cultures crossed, as Vhò culture and SMP. To further emphasize the importance of this site, it is possible to affirm that «the hamlet of Lugo di Grezzana represents a key-site to comprehend the diffusional dynamics for the Neolithic economy and ideology in Northern Italy» (Pedrotti et al., 2015).

1.3 Specific Geoarchaeological Aspects

It is important, for both the archaeological and geomorphological aspects, to define a geoarchaeological framework and identify specific features of the area taken in consideration. In fact, a broader knowledge regarding the climate and environmental aspects of the epoch considered in the research will definitely help in the understanding of the choices of human groups, in the definition of settlement patterns and in the development of specific cultures.

As said before, the period comprised in this research spans all over the Neolithic according to historic-cultural terms, but at the same time it is possible to define this epoch in geological terms, naming it as the Atlantic chronozone of the Holocene.

The Holocene is the youngest recognized interval of geologic time that constitutes the Quaternary Period, defining the last 11.700 years. This epoch is generally characterised by the most recent interglacial interval of the Quaternary period (Britannica, 2008). Within the Holocene there are five chronozones: each of them, and their succession, are characterized by changes, triggered by climate or humans, which have defined the appearance and the evolution of human groups. As far as it concerns this study, the focus is centred on the Atlantic chronozone: spanning between 9.000 and 5/6.000 cal. BP (about 7.150 and 3/4.150 cal. BCE) (Wanner et al., 2008). This period is also defined as hypsithermal due to the general presence of warmer conditions at Northern mid to high latitudes. However, the overall era still presents local climatic fluctuations as responses to major events (Wanner et al., 2008). It is possible to reconstruct these changes, specifically in Northern Italy area, thanks to different proxies as glacier advance and retreat analysis, speleothems, lake-level changes, variations in the vegetation, but also orbital, solar, volcanic, and greenhouse forcing.

Glacier advance and retreat

The movements of glaciers are the response to variations in their mass balance, in function of temperature changes in summer months, differences in precipitation during winter months and the time that passes until a new equilibrium is reached by the glacier. Considering the Alpine glaciers due to their reduced size, they are particularly sensitive to short-period variations. The variation of glacier extent is analysed taking in consideration the position and age of frontal and lateral moraines, the limits of the trimlines and the causes that defined mass balance differences (Antonioli et al., 2000). The study of moraines and their characteristics is possible thanks to radiocarbon analysis, which is a valued method as long as organic matter from terrestrial plants and bones is available. Moreover, if the death of the organism, used to date, is caused by mass movement, it allows the direct dating of the event (Soldati et al., 2006). Still, dating with an accuracy under a century using ^{14}C is rare, and

often it is more used an indirect dating (*ante* and *post quem*) with the help of other disciplines as dendrochronology, limnology and stable isotopes geochemistry (Antonioli et al., 2000).

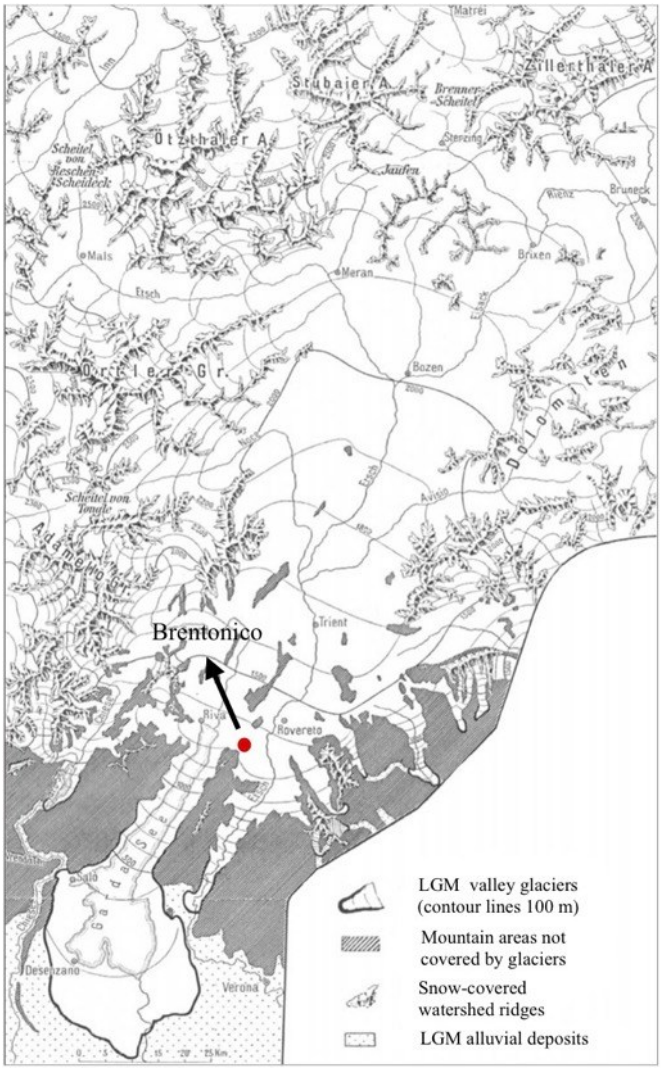

Figure 8 The historical reconstruction of the Trentino-Alto Adige region and nearby areas during the last glacial maximum LGM (modified from Penck & Brückner 1909).

Speleothems

Stalagmites, stalactites, flowstones and cave concretions are important natural archives of climate variations with a high resolution (up to years) and assure the impossibility of biological reworking. Speleothems continuously record environmental and climatic changes within their isotopic structure, through $\delta^{18}O$ and $\delta^{18}C$ present in growth laminas. The δ^{13} of carbon permits to identify and store climate but also vegetation changes, induced by rainfall and temperatures (Antonioli et al., 2000).

Orbital, solar, volcanic and greenhouse gasses forcing

Several information about climate changes and their consequences can be deduced by the analysis of different forcings, which proved to be able to condition major events. Considering the orbital forcing, this is the «amount of solar radiation arriving at the top of the atmosphere related to the energy output

from the Sun», combined with the position and orientation of the Earth with respect to the sun. If the amount and consequences of the orbital forcing is possible to be calculated, more difficulties appear with the reconstruction of solar activity, due to the changes in Sun radiations emitted. Large volcanic eruptions are able to emit hundreds Tg (teragram) of insoluble silicate matter and gasses into the troposphere and stratosphere. then, the silica matter (tephra) quickly settles out the atmosphere. In this case the CO_2 contribution is minor, but the acids formed from sulphur gasses (SO_2 and H_2S) remain for a longer time and determine climatic perturbations (Wanner et al., 2008). Finally, the measurement of CO_2, CH_4 and N_2O allows for the identification of small but consistent variations: according to Broecker et al. (2001) carbon dioxide and methane are associated with a small change in the global mean temperature, or with the increase of Ocean's carbonate chemistry.

Vegetational variations

Information regarding changes in vegetation can be obtained through palynological analysis, as a consequence of climate changes or influenced by anthropic activities. However, it is hard, if not impossible, to recognized typical vegetation types for a specific time interval in the Holocene or for large regional areas. In the same way, it appears complicated to identify dynamics and vegetation changing times for a great area. An explicative example concerning the diachronicity of biological phenomenon in the Italian peninsula is represented by the presence and development of *Fagus*: in the Central-Southern part of Italy the presence of this species was already testified in the Late Glacial period and over the board, so that it was impossible to distinguish clear migration routes. On the other hand, in Northern Italy there is a progressive movement of *Fagus* from East to West, following two main directions: one arriving in Piedmont region around 6.000 cal. BP, and the other testified in Liguria region around 4.000-3.000 cal. BP. (Antonioli et al, 2000, Soldati et al., 2006).

Lake - level fluctuations

Variations of lake-levels give information of climatic-environmental changes through the analysis of their sediments which are enriched in organic matter. Those, in fact, can be dated using radiocarbon and in return they provide a knowledge of the hydrologic balance of the main basin. The balance is determined by the difference between the volume of water entering and that leaving the basin, influenced by several factors' variations (Antonioli et al., 2000). Lake-level changes are driven by climatic parameters affecting precipitation and evaporation, but also geomorphological phenomena, hydrology of the catchment and human impact on vegetation. The analysis that can be made in order to reconstruct these differences in lake-level, and to assess the possible causes, comprise grain size analysis, pollen and diatom analysis, the study of macroscopic components of lake marl, and the observation of eroded surfaces marked by pebble accumulations. Several studies were conducted on the peat-cores from lakes all over Europe, including Northern Italy, to reconstruct past moisture

conditions, and other climatic phenomena. Among those studies, analysis conducted on the Lake of Ledro is explicative for the North Italian area: the relatively small lake is located on the southern slopes of the Alps, approximately 35 km from Brentonico, is surrounded by mountains and very close to the northern extremity of the Lake of Garda, which influences the environment with its mild climatic condition. The resulting information taken from this lake show coarser deposits in the near-shore areas, sign of a high hydrodynamics within a shallow water, and organic deposits. The frequency of plant macroremains and mollusc shells allows us to get information about the depositional environment, while the unconformities between sediment layers indicate abrupt changes in sediment deposition, corresponding to a lowering of the lake. Comparing the studies conducted in lakes of Northern Italy with the ones in Southern Italy, between 11.600 and 9.200 cal. BP the Lake of Ledro shows lower water levels, probably due to the previous presence of a morainic dam during the Last Glacial Maximum which, during the deglaciation, incised the area lowering the regional base level of erosion. These characteristics of Lake of Ledro suggests that, during the Early/Mid-Holocene, in Northern Italy there were dry summer conditions (lower water table) while the trend of generally high lake-level, during the Late Holocene, may reflect the orbitally-driven induced changes in summer insolation and was accentuated by human impact (Magny et al., 2012).

Keeping in mind that the period under investigation is, considering the geological chronology, within the Atlantic chronozone and therefore during the Holocene Climate Optimum, it is necessary to give a brief introduction on the soils developed in Northern Italy, and specifically in the Trentino Alto-Adige region, within this time. The geomorphological and pedological evidence present a general moment of biostasy, characterized by soil stabilization and the beginning of pedogenesis (Cavulli, 2020; Cremaschi, 1987). Moreover, it is recognised that the characteristics of paleosols developed during interglacial periods as «the effects of weathering and soil formation of a relatively short warm period may easily surpass those of a long cold period», as affirmed by Remmelzwaal (1978). The North of Italy, particularly the Po Plain and its surroundings, underwent different processes: the Emilian Apennine experienced a stop in the progression of fluvial fans and the accumulation of fine deposits in the plain, developing rubified Alfisols. North of the Po river, the so-called Livello Fondamentale della Pianura developed with rubified Alfisols on both the distal and proximal portions of the alluvial fans. In Central Alps and in the upper Adige Valley, there were Late-Mesolithic and Neolithic soils rich in fine fractions, interpreted as a slowing of sedimentation (Cremaschi, 1990).

Several studies have been conducted in the Po Plain in order to understand the development of soils and their relationship with Neolithic and later settlements with the help of gearchaeological and

sedimentological analysis. Excavations and research conducted by Cremaschi (2013) in the Mantua plain show the presence of highly organic soils in Neolithic stratigraphy, evolved during the Climatic Optimum. This situation has been then compared with others observed in Friuli Venezia Giulia, Emilia and Piedmont regions. More specifically, micromorphological analysis exposed the presence of microlaminated and oriented clay coatings, alternated to coarser silt and fine sand coatings containing charcoal fragments. These elements indicate the presence of a forest cover alternated to brief periods of deforestation and an agricultural use of the land. Again, Cremaschi observed that the Neolithic occupation does not develop over an A horizon, but directly over a B horizon characterized by dark colour and plastic consistence. The dark tone of the sediment, spanning from a dark brown to a greyish-black, is linked to the organic matter and the mineral fraction present in the humification process, and it is attributed as characteristic of Neolithic anthropic deposits (Cavulli, 2020).

In the Alpine area, slope stability and pedogenesis developed only during the Atlantic period, as already in the successive Sub-Boreal it was present a general instability situation. Unfortunately, few pedological data are available for the Trentino Alto-Adige region, and the few existing maps do not allow a clear identification of soil type mainly due to the great variability of reliefs which conditions the positioning of soils within the map. Generally, it is possible to say that three main typologies of soil are present: soils formed on carbonate rocks, spread in the pre-Alpine and Southern Alpine area, soils formed on metamorphic substrate, almost exclusive of South-Tyrol, and soils formed on porphyric rocks, on the East side of Adige River. Still, other typologies can be present, such as alluvial lands in valley floors and glacial morainic located in mountainous areas (Di Pillo, 2023). This latter is particularly prominent in the Southern part of Trentino, expressed in the moraine ridges of Garda Lake. This moraine ridge changed its petrographic composition from an older prevalence of limestone, with volcanic rocks and granitoids as subordinate, to more recent granitoids, metamorphic rocks and porphyries from Alto Adige area (Cremaschi, 1987). Considering the Soil Map for Trento province (1965), the area under investigation in this research presents a prevalence of Brown Forest Soils-Rendzinas. However, conscious of the fact that geological maps for this area mainly represent pedological associations and not specific types which can differ within meters (Di Pillo, 2023), it is necessary to briefly say something also about the surrounding soils. Therefore, there will be a short explanation about brown calcareous soils-Lithosol and Acid Brown soils, other than Rendzina soils. Those three soil typologies are all part of one group, the Brown Soil group: generally, brown soils are good quality terrains, rich in oxides and hummus, which can also develop with a calcareous matrix. Brown Calcareous Soils are usually present on gentle slopes or at their foot, where glaciers are not present but there are forest covers, or on slopes where erosional processes are advanced. These soils, generally, have a higher thickness respect to Rendzinas, and their characteristic

element is weathered Bw horizon. At lower altitudes, up to 2.200-2.300 m a.s.l., where harsh morphologies and erosive processes are present, it is possible to find Rendzina Soils: those are calcareous, eroded by oxides and rich in humus, which determines the dark brown or black colour. Their pH is neutral or slightly basic, and they are frequent on Dolomites and in the pre-Alpine area (Di Pillo, 2023, Sartori et al., 1997). Finally, Acid Brown Soils are located on siliceous-crystalline formations, between 700 and 1.200-1.300 m a.s.l., on glacial and post-glacial deposits, in the area comprised by the pre-Alpine and continental climate. These soils presents a Bw horizon, brown in colour and macrostructured, with a rather acid superficial AE horizon (pH 4.5-5.2) which decrease along the profile (Sartori et al., 1999).

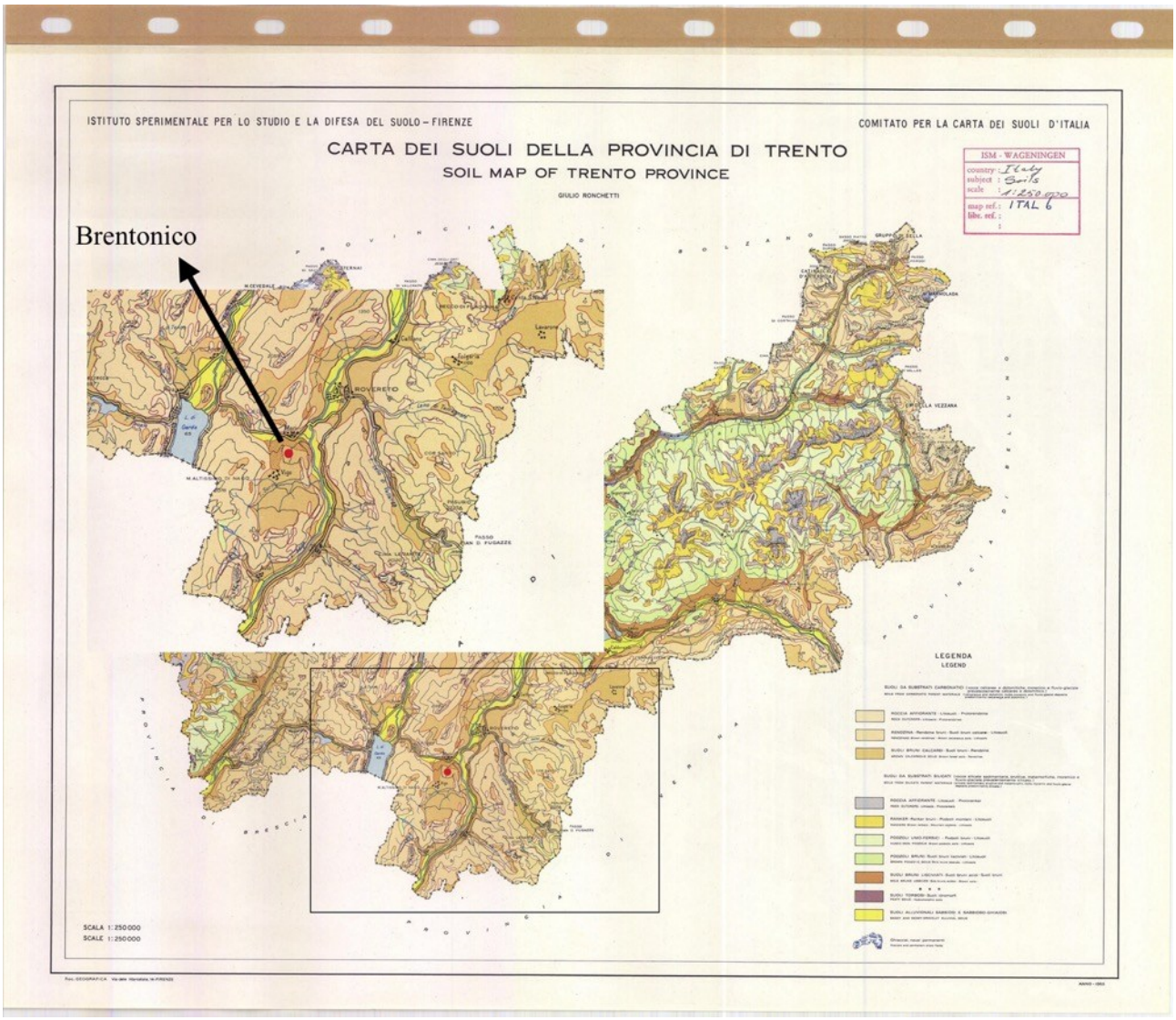

Figure 9 Soil Map for Trento province (1965), modified.

Similarly to this study, in the Trentino Alto-Adige and Veneto area, several other investigations were performed. Some of these presented comparable characteristics with the studied site of Brentonico. There will be, now, a brief sedimentological discussion of two of the most relevant sites for the Neolithic period, already cited in this work, which share similarities with Brentonico site.

The archaeological site here described is the one of Lugo di Grezzana, located on a fluvial terrace between Lessini Mountains in the area of Verona (about 50 km from Brentonico). Sedimentological analysis show pedogenetic fine alluvial sediments, with erosion and fine colluvium as indicators of slope instability (Cavulli, 2020). In the work of Angelucci (2002) a micromorphological analysis was conducted on selected samples from different spots within the site, in order to have a wider vision of the sedimentary dynamics. This allowed for the characterization of the site evolution in terms of sedimentology and pedology, and the role of humans in the modification of the environment. Finally, micromorphological data showed a succession of pedogenesis and biostasy during the Middle and Upper Holocene. The first phase of this settlement, dated to the half of VI Millennium cal. BCE, was located on a black paleosol, characterized by a strong weathering probably caused by human's impact. However, signs of colluvial episodes show a stop in the evolution of the site, to be then resumed starting from 4.900-4.800/4.700 cal. BCE with an occasional frequentation (Pedrotti et al., 2015).

The other site is located in the clay quarry of Quinzano Veronese, West to the city of Verona. Here it is present an important SMP culture Neolithic site which was investigated with geoarchaeological analyses: in fact, micropedological examinations allowed for the definition of this site stratigraphy and its post-depositional processes. What emerged was a site resting above a rubified Alfisol, similar to the one found in the Mantua plain, established on Late Glacial sands of the Adige River. The conclusions obtained from this study presented the development of the Neolithic settlement on a surface already characterized by stability during the Lower Holocene, while during the Sub-Boreal and Sub-Atlantic period these deposits were submerged by detritus produced by the erosion of Mount Lessini (Cremaschi, 1990).

2. Materials and methods

Samples were collected in the field by archaeologists of the University of Padua during different visits carried out in 2023-2024. The first set of samples was collected in August of 2023: among those there were nine bulk samples, nine samples for micromorphology, and seven charcoal samples for dating purposes. All specimens were taken from the Southern portion of the site: bulk sample from 1 to 6 are from Section 2 (Fig. 10), while samples from 7 to 9 come from Section 4 (Fig. 11). In May 2024, a second visit was paid to the site, during which four more bulk sample, five block for micromorphology and two charcoals samples, were taken. In this case they were taken from the E-W Section, again represented in the figures below (Fig. 16-22). Finally, the last visit carried out also in May 2024 provided two samples (one bulk and one for thin sections) and one charcoal from a possible Mesolithic hearth.

Figure 10 Field image of the South Profile, Section 2.

Figure 11 Field image of the South Profile, Section 4.

2.1 Thin Sections

All the procedures applied for the creation of thin sections followed the ones outlined in Murphy (1986).

Sample were collected as undisturbed blocks, i.e., blocks that are collected as whole and oriented to keep a relationship with their context. In some cases, after being carved out, samples were wrapped in plaster bandages, especially when the sediment was particularly loose and incoherent, and then placed in newspaper and tape. Once samples arrived in the laboratory, at the Department of Geosciences of the University of Padua, packages were cut open for a sufficient area to permit the removal of moisture before impregnation. In this situation, samples were bigger than necessary and therefore they were trimmed and shaped to fit a more appropriate dimension to that of thin sections (Fig. 12). After a final drying period in the oven at 40° C, depending on the necessity of the material,

Figure 12 Example of micromorphological block for thin section, before cut and impregnation.

samples begun the impregnation process. All samples were immersed in a four-component epoxy resin (TAAB Transmit Resin) and then placed in a vacuum chamber to make it easier for the resin to penetrate into the sample. Once samples hardened, next steps included cutting and thinning of blocks: samples were placed in a saw machine with a large diamond blade and cooled by a water spray, and a slow even pressure was used to pull the block through. The cut blocks (chips) should be at least 4-5 mm thick, and about 90x60 mm in dimension. Another layer of resin, here a two-component thermosetting epoxy resin, was applied on one side of the chips allowing a thin section glass to adhere. The chip could now be placed in a metal ring where a powder abrasive made it perfectly flat. Then,

the excess material was removed by means of a cutoff saw. Lapping and polishing were then carried out using a BROT thin section machine, until a thickness of 30 µm was reached. The thin-sections were then hand finished shall their thickness be still too high.

The analysis conducted on thin sections involved the use of an optical polarizing microscope, composed of a turning table, two polarizing filters (nichols) positioned above and below the table. By placing the upper nichol, called analyser, it is possible to observe the sample in XPL (crossed polarized light) or crossed nichols, on the contrary the observations are conducted with parallel nichols or PPL (plane polarized light) (Cremaschi, 2006). In this research, thin sections descriptions were made using terminology of Stoops (2021). In the description of organic and plant residues present in thin sections, a specific reference table was used in order to better differentiate the different classes (see table below).

Table 1 Reference for organic and plant residues dimensions.

Organic/plant residues	Size
Charcoal	250
Tissue	50 x 250
Punctuations	50

2.2 Granulometries

Bulks samples were dried in the oven at 70° C, the materials were weighted and transferred from plastic bags into beakers. here, specimen were immersed in distilled water in order to disintegrate larger aggregates. Subsequently, the organic fraction present was digested using the Wet Peroxide Oxidation process: this has been adapted from the classic Fenton reaction by adding equal parts of hydrogen peroxide (H2O2) 30% and a water solution (0.05 M) of iron(II) sulphate heptahydrate (FeSO4 • 7H20) as catalyzer. To preserve a reducing environment, <1% of sulfuric acid was added, continuing with this practice until the end of the reaction.

Once the reaction completed, the granulometric distribution of sand fraction (>63 µm) was estimated through sieving using a steel sieve column (Fig. 13) with passing mesh of 2 mm, 1 mm, 710 µm, 500 µm, 250 µm, 125 µm, 100 µm, and 63 µm diameter. The sieving was conducted in wet, through mechanic action and under a weak water stream. All the sand fractions (above 63 µm) were then dried in the oven, while the fine fraction (<63 µm) was collected by percolation in buckets and left settle, to be then moved in beakers placed in the oven to dry. Every fraction was weighted, only the material with diameter smaller than 250 µm was collected in plastic bags and stored for eventual further analysis. To determine silt and clay percentages within the fraction below 63 µm, it was used a laser diffraction particle size analyser, Malvern Mastersizer 3000 Hydro (Fig. 14). The following settings have been applied:

Particle type: non-spherical
Particle name: China Clay (refractive index: 1,555. absorption index: 0,01. density (g/ cm³): 1)
Dispersant: Water (refractive index: 1,33)
Measurement duration (s): 10
Measurement sequence: number of measurement: 5
Measurement obscuration settings: 5 (lower limit %) – 15 (higher limit %)
Post-measurement clean sequence settings: Custom, 3 cycles, ultrasound
Analysis settings: General purpose
Results settings: Limited between 0,005 µm and 400 µm

Volume distribution: User sizes for histograms and tables (Logarithmic: 0,1; 0,158; 0,251; 0,398; 0,631; 1; 1,58; 2,51; 3,98; 6,31; 10; 15,8; 25,1; 39,8; 63,1; 100)

Figure 13 Sieves used to separate different clasts sizes.

Figure 14 Tank beaker of the Mastersizer 3000.

To perform this analysis, a small sample quantity was dispersed in about 30 ml of deionized water together with a smaller amount of sodium hexametaphosphate Na6[(PO3)6] as deflocculating agent. The resulting mixture was shacked and stirred and later extracted with a pipette. The sample was injected into the tank beaker of Mastersizer until reaching the obscuration level of about 8%. Of particular importance is the sample extraction conducted several times and at different depth, keeping the mixture always in movement. This precaution is taken to avoid or minimize statistical errors given by particle decantation. Once the specimen (ex. Bre_4) was injected into the tank beaker and the right obscuration level is reached, a cycle of ultrasound is operated for 60 s to disaggregate eventual residual pseudoparticles. At this point, the sample measure was carried out and the machine proceeded to collect five measures and their average (ex. Average of Bre_4_a). Successively three cycles of cleaning were performed, and a second round of analysis of the same specimen was carried on (ex. Bre_4_b). This operation was repeated three times, for each specimen (ex. Bre_4_a,b,c), and the final data resulted from the average of the three averages values (ex. Average of Bre_4).

To obtain the granulometric distribution of each sample, all the weight data from sieving and the percentage data from laser diffraction particle size analyser were united. Firstly, it was necessary to know the weight of the organic component destroyed during the chemical digestion and the possible dispersion of the inorganic sediment occurred by error during the reaction or sieving. The possibility of losses within the process can be violent, especially in case of samples rich in organics.

Every weight data from the sieving was summed and compared with the starting sample weight and considering as total (100%) the resulted weight of the different inorganic fractions, these weights were converted into percentages.

Considering the fine fraction (<63 µm) analysed through the laser diffraction particle size analyser, the data regarding the average of the three measures of all samples were exported and distributed in percentages between ten ranges: 250-500 µm, 125-250 µm, 106-125 µm, 63-106 µm, 50-63 µm, 10-25 µm, 4-10 µm, 1-4 µm, 0-1 µm. The fractions above 63 µm were included to recover possible particles escaped from sieving. In order to add these data regarding granulometric fine fractions to those concerning coarser fractions, the percentages for the subdivision in ranges proportional to the total percentage of the fine fraction (collected from the weight measure) were recalculated. In this way, it was possible to obtain percentage values of all granulometric classes calculated on the Tm. Based on these data, cumulative undersize curves, regarding the granulometric distribution, were plotted and they will be exposed in the next chapter.

2.3 Radiocarbon dating

Radiocarbon dating is a radiometric method to date using ^{14}C which allows the determination of the age of materials containing carbon, up to ca. 50.000-60.000 years BP. This technique requires a very small amount of specimen, giving back precise data that provide the age of sample death computed by the universal decay curve: $t = 1/l \times \ln(N_0/N) = 8033 \times \ln(^{14}C_0 / ^{14}C)$. ^{14}C is the original amount of carbon present in an organism at the time of its death, and it is presumed to be in balance with the atmospheric carbon (Artioli, 2010). Although nowadays the correct half-life of radiocarbon has been indicated to be 5730 years, the conventional age still follows Arnold and Libby model (1949), who based it on a measured half-life of $^{14}{}_{6}C \rightarrow {}^{14}{}_{7}N$ reaction.

For this research four samples have been radiocarbon dated. Several specimens were collected from different areas of the excavation site (as reported in Fig. 15) following a standard procedure in order to maintain the sample as integer as possible and to avoid contaminations. The analyzed organic material, in this case, come from charcoal and wood fragments which generally require 5 to 10 mg for an investigation through AMS (Accelerator Mass Spectrometry). Once the sample is selected, this is usually collected in double bags to avoid further contact with the atmosphere or other pollutants. Touching the specimen with bare hands was also avoided. Sometimes, once samples arrive in the laboratory, a sub-sampling may be necessary depending on quality and volume of charcoals. Before dating the samples, as in this case, wood fragments and charcoal were determined under a reflected light microscope: the sample is investigated in its three sections, Transverse (TS), Tangential Longitudinal (TLS) and Radial Longitudinal (RLS). The identification is made by comparison with published sources and with modern charcoal reference material (Veal, 2014). The analyzed anthracological remains were eleven, however due to different variables only in seven cases it was possible to determine the species or genre.

A further selection was conducted on the seven samples to determine which were the best and most significant to provide dates. Four samples were selected: BRE 14C-4 and BRE 14C-5 are both *Carpinus Betulus* and were collected from US 6 (US 20 according to the company report). BRE 14C-9 and BRE 14C-10 (or BRT23PALÙ C330, as it was collected by the company in charge of the excavation) are respectively *Salix*, from US 51, and *Abies alba*, from US 321.

Samples BRE 14C-4 and BRE 14C-5 were sent to the laboratory of Aahrus University to be dated, while sample BRE 14C-9 and BRE 14C-10 were sent to the laboratory of the University of Groningen. Both laboratories used a calibration with 2σ (95.4% of probability) precision, and OxCal v. 4.4 (Bronk Ramsey, 2009. 2020) as calibration program. The radiocarbon (14C) ages were

calibrated using the IntCal20 curve (Northern Hemisphere atmospheric. Reimer et al. 2020). The resulting dates will be shown in the next chapter.

3. Results

3.1 Thin section description

South Profile, Section 2

US 2 (US 3): 5YR 3/3 dark reddish brown. clay. moderate angular and polyhedric structure. Skeleton 10% 3-15 mm. Frequent rounded roots. gradual lower limit.

US 3 (US 3): 5YR 4/2 dark reddish grey. Clay. Skeleton about 5% and pores <1 cm.

US 4 (US 4): 5YR 3/2 dark reddish brown. Clay, weak angular polyhedric structure. Skeleton 5-10% 5-20 mm. Frequent roots also centimetric. Planar clear lower limit.

US 5 (US 42, US 43): 7.5YR 3/1-3/2 very dark grey/dark brown. Clay. Weak coarse angular and polyhedric structure. Skeleton about 5% rounded pebbles 3-5 cm. Rare fine roots. Planar and gradual lower limit.

South Profile, Section 4

US 6 (US 20): 5YR 3/1 very dark grey. Clayish silt. Weak angular and polyhedric structure. Skeleton 5-10% also decametric pebbles and flints. Planar and clear lower limit.

US 7 (US 5): 7.5YR 5/6 strong brown. Silty clay with scares sand infiltrations. Rounded pebbles 1-5 cm abandoned in variable proportions. Possible massive calcareous lithorelicts. Planar and clear lower limit.

US 8 (US 6): 7.5YR 5/8 strong brown. Clay. Angular and polyhedric structure strongly separated. Skeleton 5-10% rounded pebbled 2-5 cm, toward North increase in dimension and lumps. Calcareous lithorelicts. Undulated and abrupt lower limit. Coatings 7.5YR 4/1 dark grey on peds faces.

US 9 (US 8): 7.5YR 4/6 strong brown, sandy clay/clay loam. Angular and polyhedric structure with pressure faces well expressed. Abundant skeleton 1-2 cm, sub-angular and sub-rounded. All rocks are white rocks. Crumbs of calcareous lithorelicts. Lower limit not reached.

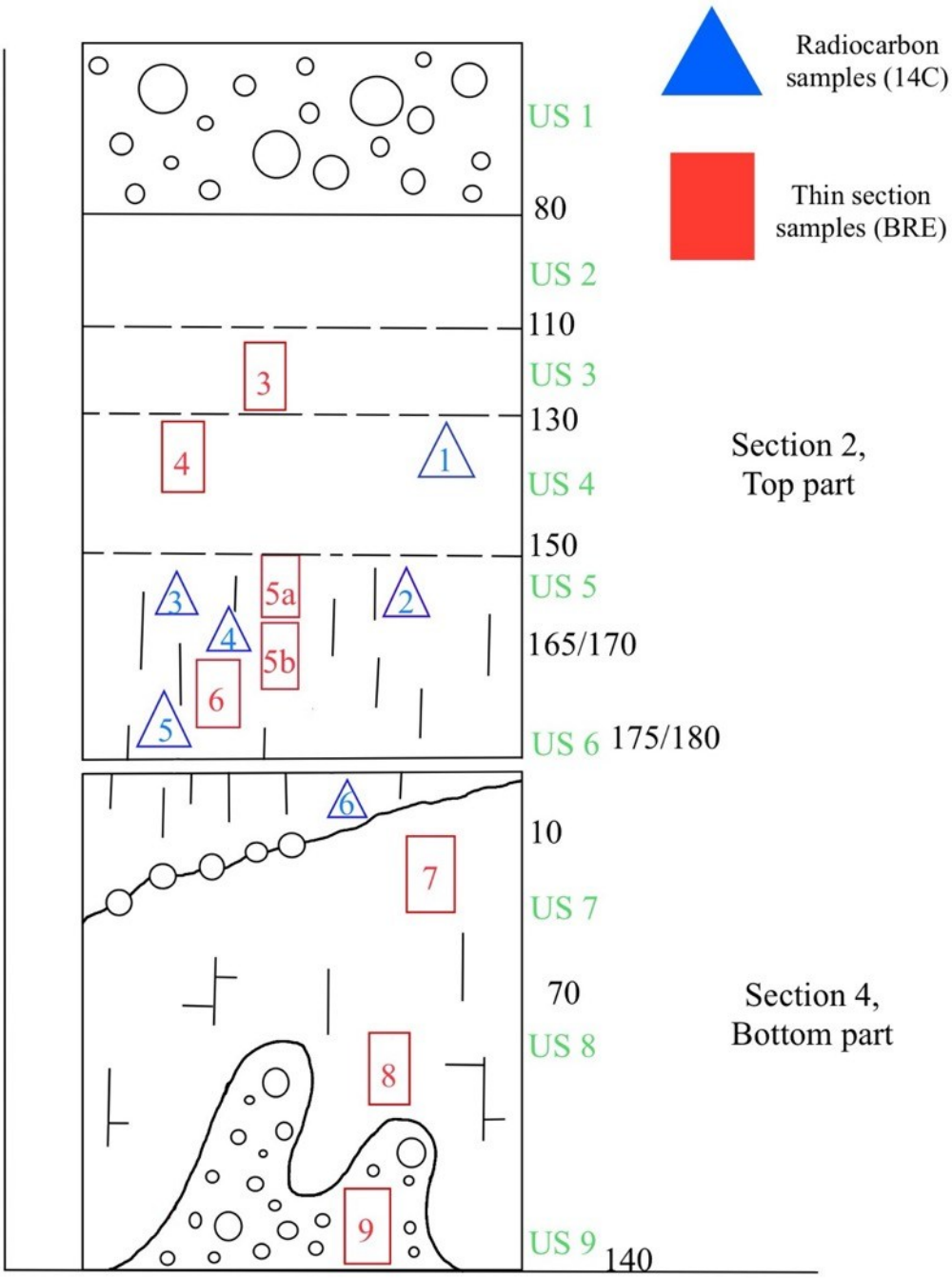

Figure 15 Illustration of the whole sequence (South Profile) with the location of thin section and 14C samples.

As said before, a total of fifteen samples for micromorphology and fourteen bulk samples were collected, not all of them were analysed. The chosen samples were selected as part of the stratigraphy sequence, able to solve the questions of this research. However, images of these samples and their locations are represented below.

Figure 16 Field image of the pyrotechnological structure and location of thin section samples.

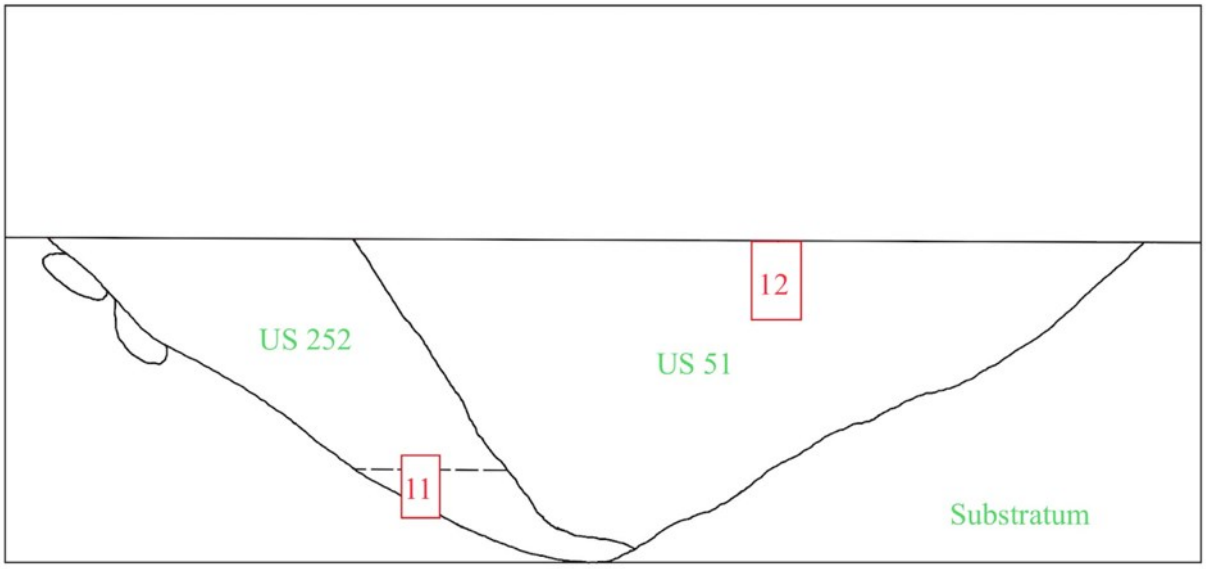

Figure 17 Illustration of the pyrotechnological structure and location of thin section samples.

Figure 18 Field image and sample location of BRE 13.

Figure 19 Field image and location of the sample BRE 14.

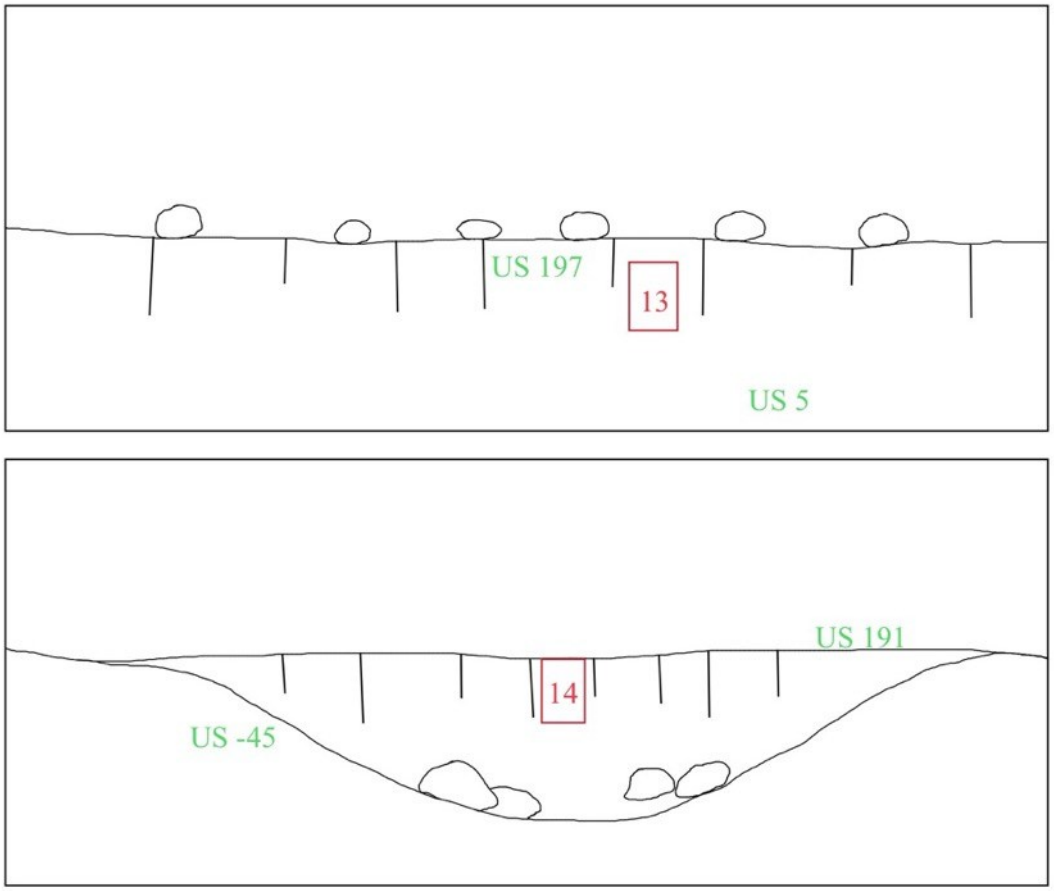

Figure20 Illustration of the collocation of samples BRE 13 and BRE 14.

Figure 21 Field image of the collacation of sample BRE 15.

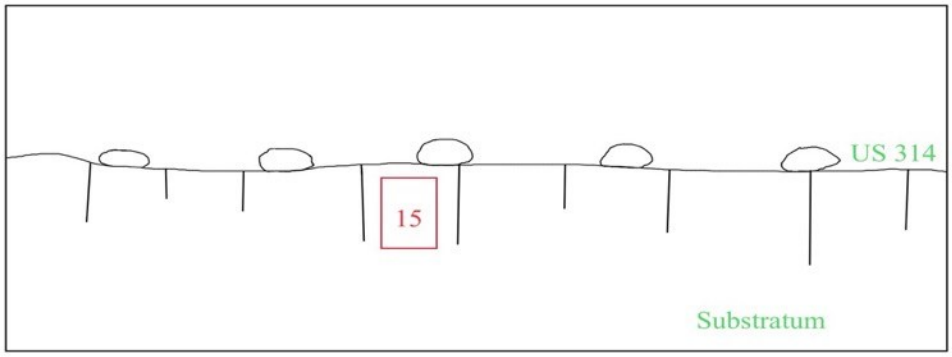

Figure 22 Illustration of the collocation of sample BRE 15.

3.2 Thin section description

Eleven thin sections were studied under the microscope. The choice has been dictated by questions and goals of the research, which led to the identification of three main groups of samples.

The first group analysed is composed of five specimens: BRE 5b, BRE 5a, BRE 4 and BRE 3. They all come from the Southern Profile, Section 2 and as evidenced on field, correspond to clay colluvium and soil above the underneath red substratum. Two of the radiocarbon data available indicate that these are the most recent sediments present in the sequence. The main micromorphological characteristics of the thin sections from this group will be outlined below.
These five thin sections presents a similar inter-pedal microstructure, which range between angular to subangular blocky, and in few cases (BRE 5a) shows both. Considering the intra-pedal microstructure, again in all samples there is a prevalence of vughs, but complex microstructures can be recognized in one sample (BRE 4). It is important to highlight the presence of few peds in the specimen BRE 3, which the most recent of the sequence. The c/f pattern is single spaced porphyric, except for BRE 4 which shows a double to single spaced porhpyric pattern. In the same way, all b-fabric are stipple-speckled although thin section BRE 3 also shows the presence of a granostriated b-fabric. Generally, the texture of these specimen ranges between clay loam, loam and sandy loam: the majority are moderately sorted, however BRE 4 is poorly sorted. There are different typologies of rocks, present in all the thin sections but with a difference in their amount. Among those rocks, four classes of volcanic rocks were discovered: altered orangish volcanic glass clasts. Basic volcanites with a high density of plagioclase phenocrysts embedded in a dark matrix rich in Fe hydroxides and oxides. Volcanites with altered olivine forming iddingsite embedded in a microcrystalline matrix rich in Fe oxides (Fig. 23, A and B). Acid volcanites, with light clasts and phenocrysts of plagioclase, embedded in a light microcrystalline matrix (leaning to a pinkish colour). Other than volcanic rocks, metamorphic rocks were found, as gneiss with quartz aggregates, plagioclase and muscovite, but also magmatic quartz and porphyry (especially in BRE 5a and BRE 4). Finally, organic and plant residues show an increment of punctuations percentage (considering from the oldest sample (BRE 5a) of the profile to the most recent (BRE 3). The amount of tissues in specimens varies without a real uniformity, as well as charcoal which is more abundant in sample BRE 4. Clay coatings are present in all the sequence, almost in the same amount and either dusty, impure or layered, as well as infillings are recognized as dense and incomplete. A flint fragment is present in sample BRE 5a (Fig. 23, C and D).

The other group in which it is possible to divide the specimens is composed of three samples: BRE 9, BRE 8, BRE 7 and BRE 6. They were collected from Profile 1, Section 4, which corresponds to the base of the sequence immediately above the substratum. Although sampled from another area of the site, it is possible to assign another sample to this group, this is BRE 16 which shares many features especially with the most ancient sample investigated (BRE 9). Here a brief description:
This group presents different inter-pedal microstructures as two specimen (BRE 9 and BRE 16) have a platy microstructure, whereas the others show a subangular and angular microstructure. It is important to specify the fact that the sample BRE 8 displays two different structures, as the lower part of the thin section is apedal with a massive intra-pedal microsctructure. Again the c/f pattern ranges between double to single spaced porhpyric, with the exception of BRE 16 which shows a closed porphyric pattern. BRE 9 and BRE 16 have a crystallitic b-fabric, BRE 7 and the upper portion of BRE 8 shows again a stipple-speckled and granostriated b-fabric, while the lower part of BRE 8 is characterized by cross striations. All specimen, with the exception of BRE 7, are a moderately sorted clay loam, in some cases with carbonates, as nummulites, bryozoans, and red algas probably of Eogene-Oligocene origin, micritic calcareous rocks (Maiolica) and micritic calcareous rocks with sponge spicules, ostracods and globigerinoides probably from Scaglia Rossa (BRE 9 and BRE 16) (Fig. 23, E and F). Even in this group different types of volcanic and metamorphic rocks were found, similar to the previous group but in different amounts: if in the lower layer there was a prevalence of basic volcanic rocks, already in BRE 6 it was possible to observe an increment of acid volcanic rocks. Again there is a sort of augmentation regarding organic and plant residues, starting from a very low frequency and characterized by almost exclusively punctuations in the lower thin section of the sequence (BRE 9), to see an increment (especially in tissue fragments) higher in the sequence. Clay coatings continue to be impure, dusty but in addiction are also present compound layered and layered, and limpid coatings. In the two calcareous samples (BRE 9 and BRE 16 hypocoatings of calcite are also present.

Finally, the last group contains two specimen: BRE 12 and BRE 11. These were extracted from a pyrotechnological structure located above the red horizons, in the E-W Section. The charcoal remains present in this feature gave the possibility to date the hearth, adding information to the stratigraphic sequence. The two thin section of the last group can be described as follows.
The two thin sections show a subangular blocky inter-pedal microstructure. However they differ in the intra-pedal microstructure with BRE 12 presenting a complex one (vesicular and channel) while BRE 11 is simply vughy. The c/f pattern is single to double spaced porphyric, the texture is a moderately sorted clay loam and loam. The rocks characterizing the specimens are basic volcanic

rocks, both the type with olivine altered into iddingsite and the one with crystals of plagioclase in a fine matrix rich in Fe oxides. In BRE 11 the majority of rocks were represented by these types of volcanic fragments, especially located in the lower part of the thin section, and in a higher amount with respect to BRE 12. In the same way, though both shows a stipple-speckled b-fabric, BRE 11 also presents striated b-fabric (granostriated and porostriated). As expected, the amount organic and plant residues is higher with respect to the other groups: charcoals are common, punctuations and tissues are frequent, and few organs are found.

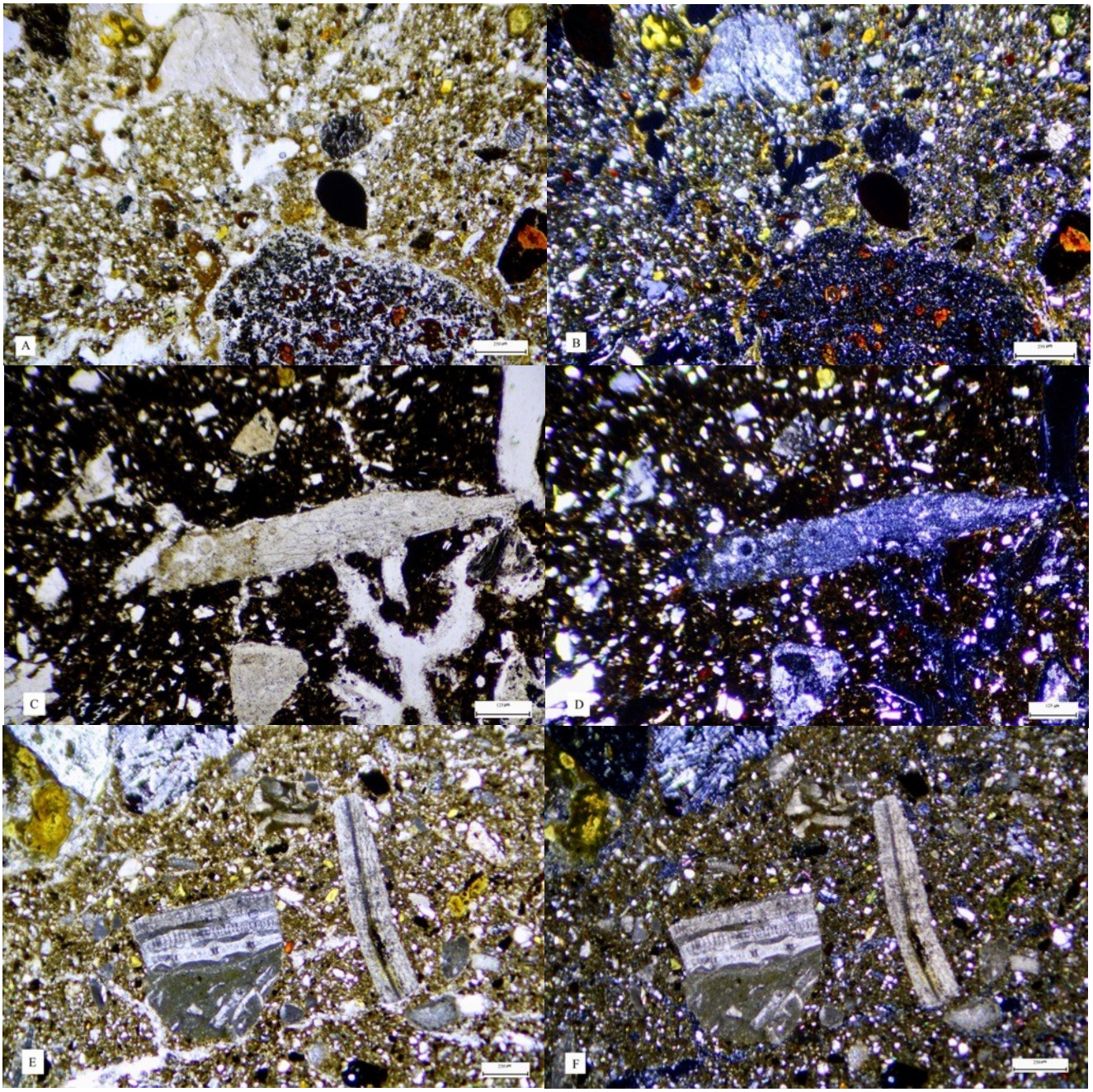

Figure 23 A: Examples of volcanic rocks embedded in a fine grain matrix (PPL), from thins section BRE7. B: Same as A but in XPL. C: Example of a chert (PPL) from the sample BRE5a. D: Same as C but in XPL. E: Examples of carbonatic rocks (PPL) from the sample BRE9.

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3.3 Granulometries

The data obtained from the granulometric analysis showed a complex of cumulative curves which, once divided into the two groups recognized on field as “red soil” and “black soil”, presented differences within the class size of the singular stratigraphic units. Looking at the curve of the whole sequence (Fig. 24) it was possible to see variations, with more or less steep curves, or different starting points of the curves themselves. The interpretation of these data will be exposed in the next chapter, however a first look at the sequences will be offered here.

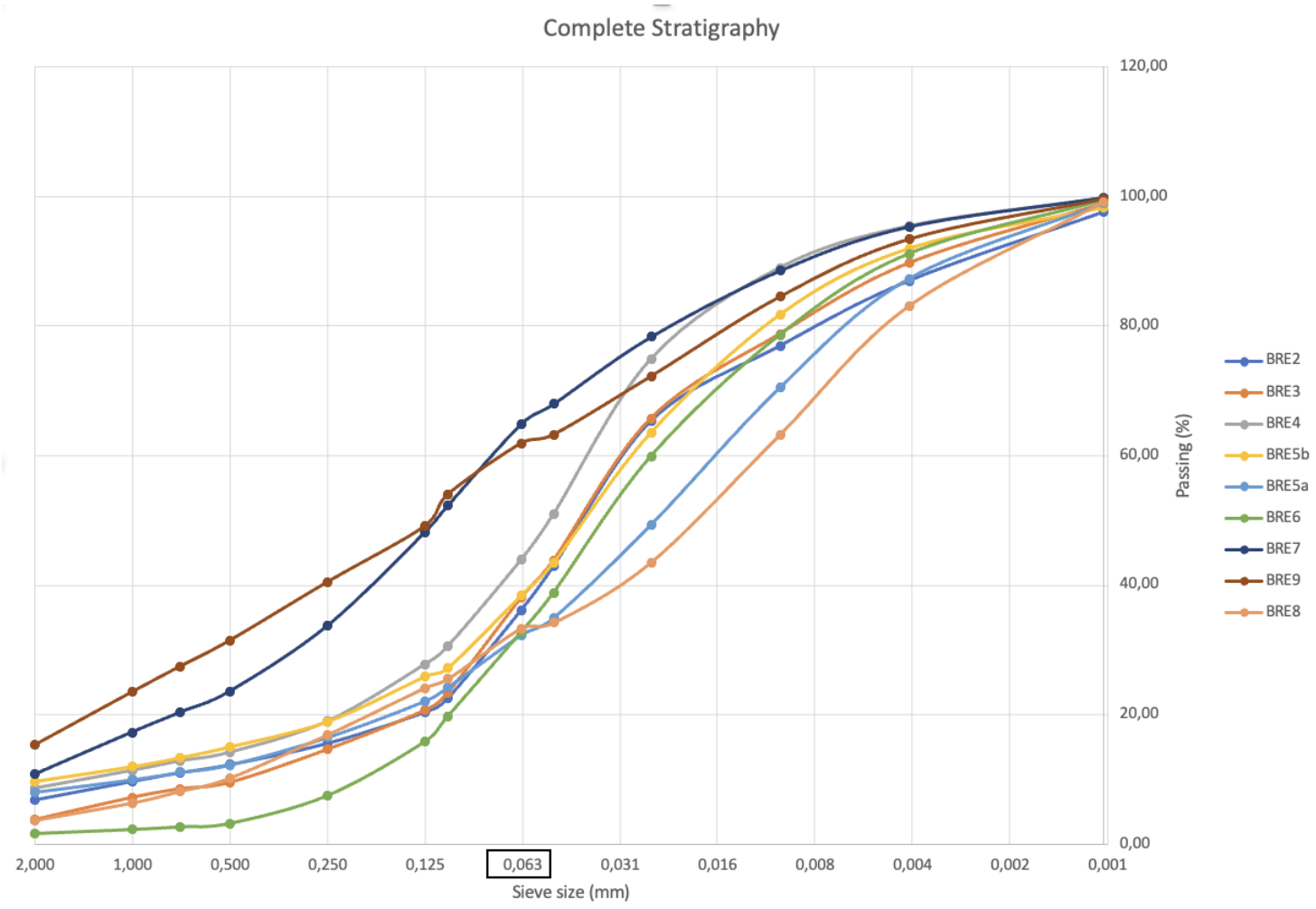


Figure 24 Granulometric curve of the complete stratigraphy.

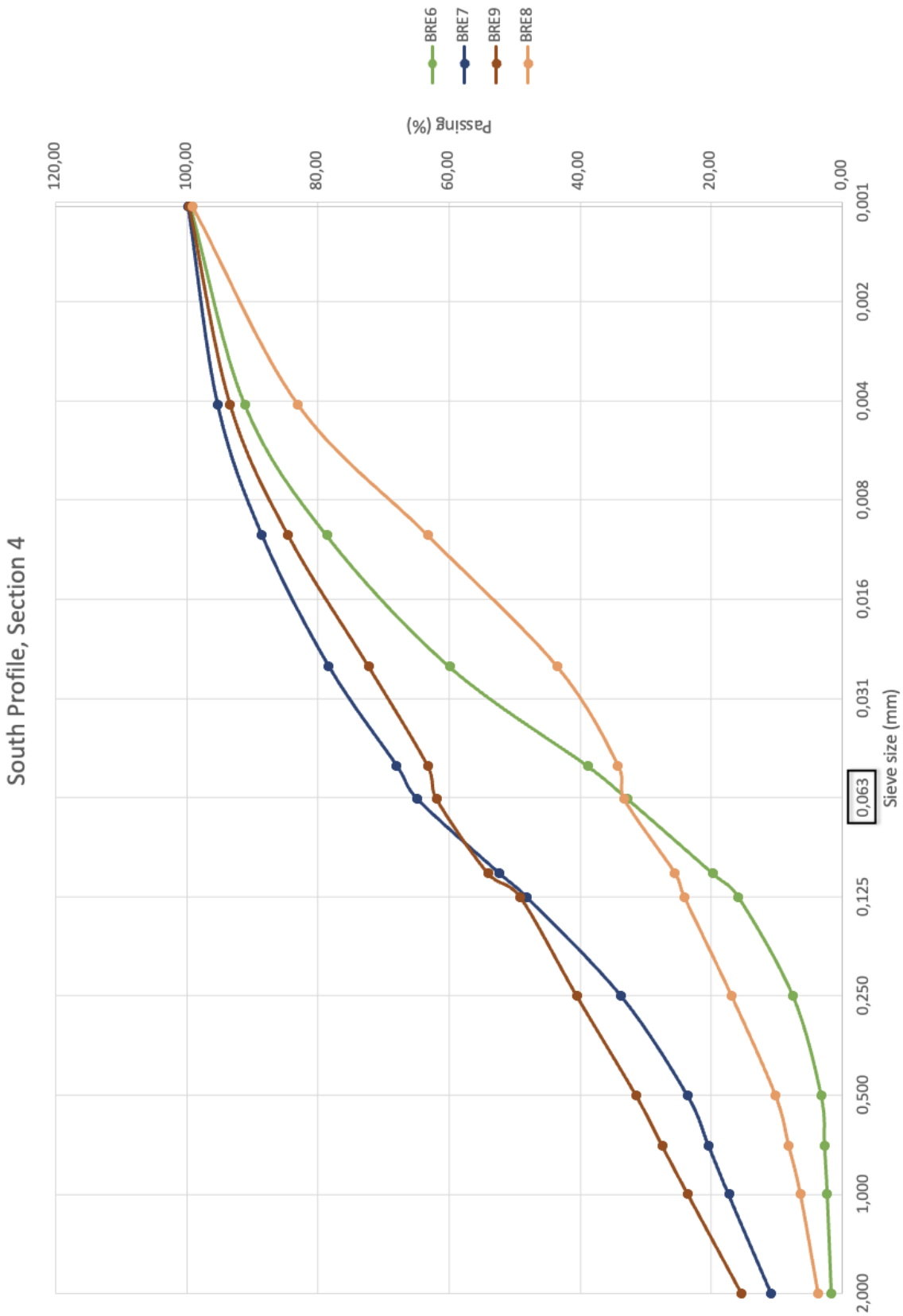


Figure 25 Granulometric curve of the South Profile, Section 4. Bottom part of the sequence.

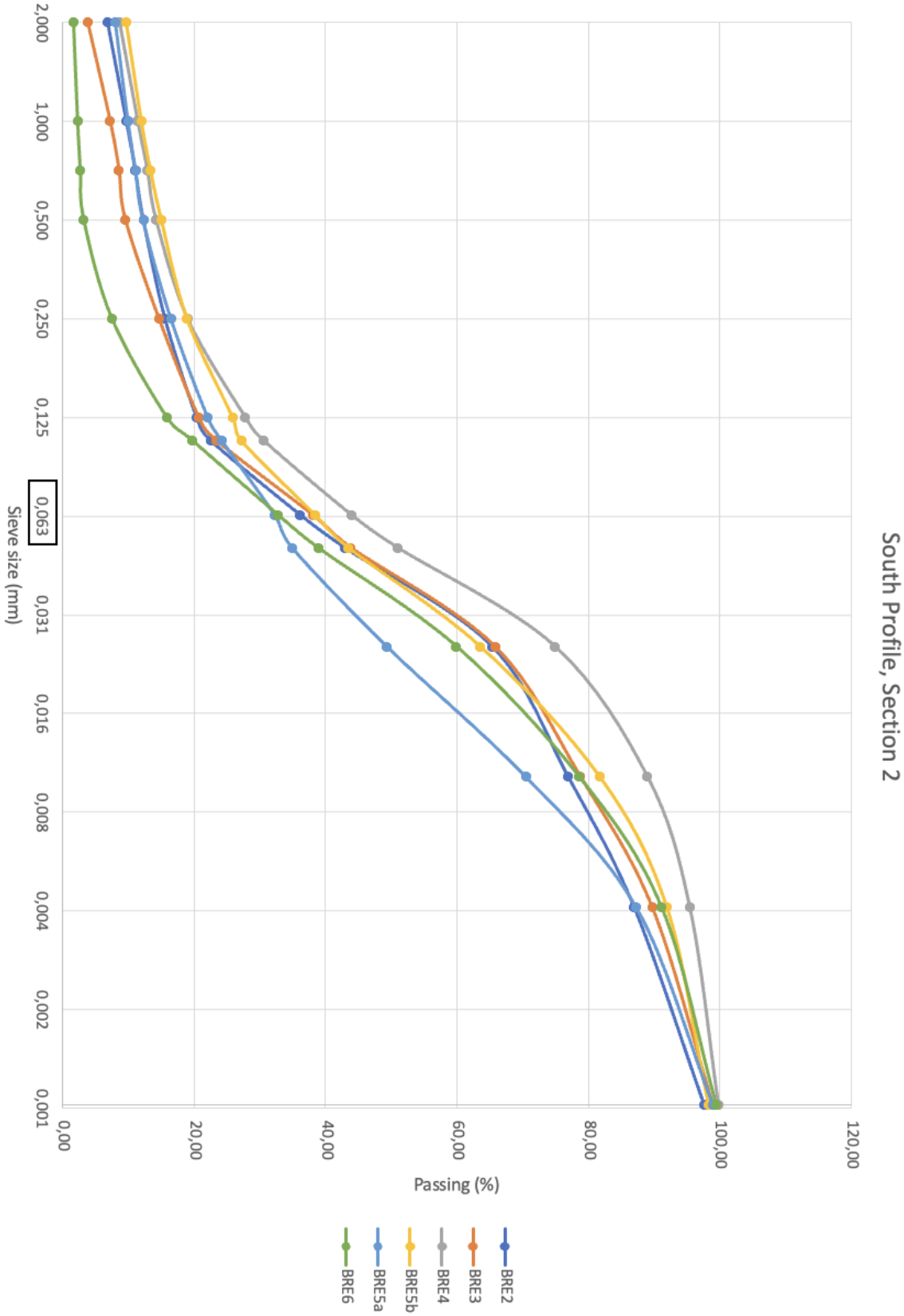


Figure 26 Cumulative curve of the South Profile, Section 2. Top part of the sequence.

3.4 Radiocarbon dates

Data results from the samples BRE 14C-4, BRE 14C-5, BRE 14C-9, and BRE 14C-10

Sample ID	Laboratory reference	Section	US	^{14}C (BP) $\pm$ 1σ	^{14}C cal. (BCE) 68.3%	^{14}C cal. (BCE) 95.4%
BRE 14C-4	48169	2	5	4803 $\pm$ 35	3639–3622 (16.8%) 3583–3531 (51.5%)	3644-3525
BRE 14C-5	48170	2	6	5706 $\pm$ 36	4602–4563 (19.5%) 4556–4493 (43.8%) 4471 – 4461 (5.0%)	4674-4635 (7.2%) 4617-4453 (88.2%)
BRE 14C-9	GrM-37424	E-W	51	5990 $\pm$ 35	4935 - 4805	4988-4791
BRE 14C-10	GrM-37425		321	6165 $\pm$ 40	5208 - 5049	5216- 4996

4. Discussion

The sequence of Brentonico shows different characteristics which allowed its subdivision in two units. each of them was the manifestation of singular events and environments. In fact, thanks to these groups it was possible to define a differentiation and division of processes already on site and further determined with micromorphological analysis and granulometries.

Starting from the oldest part of the sequence, this group (represented by BRE 9, BRE 16, BRE 8, BRE 7 and BRE 6) was defined as a red substrate on which the settlement developed.

The particularity of this group was given by the presence of evidence of periglacial processes, already visible in the field, and characterizing samples BRE 9 and BRE 16. It is known that the area of Brentonico and its surroundings were characterized by the presence of glaciers during the Pleistocene, until about the Late Glacial (17.00-11.500 years ago), and their retreat left some substantial traces (Angelucci, 2016). A first hint to suggest the occurrence of glaciers in this portion of the sequence was the presence of different traces of frost heaving (Fig. 11). Frost heaving is related to ice segregation in soils and results from freeze and thaw cycles (Van Vliet-Lanoë, 1985. 2010). The temperature of frozen soil, which was lower than the air temperature, and the inversion of thermal gradient might have stimulated the infiltration of melting water in the frozen substratum, stressing the soil and determining additional heaves (Van Vliet-Lanoë, 2010). Moving to micromorphological analysis, frost features were evidenced by the presence of a platy microstructure or lenticular microstructure, and horizontal planar voids (Fig. 27, A and B). However, in some cases also an angular blocky microstructure was observed. This could be given by the rapid cooling of clays or silty clays saturated in water. These features are usually produced after the melting of ice and while at depth platy structures form, near the surface it is possible to see a bladed structure. Platy aggregates have a size from about few tenths of a millimetre up to centimetres at depth (Van Vliet-Lanoë, 1985). Another remarkable aspect of these two samples was the occurrence of carbonates. This feature showed both in form of mineral grains of the coarse fraction (gravels and coarse sands) but also as pedofeatures: although the manifestation and distribution of calcium carbonate within mountainous soils can result more complicated with respect to other soils, some studies have already been carried out and tried to give answers to their presence and related processes (see Gargiulo et al., 2013. Bockheim and Douglass, 2006. Zagórski, 1999). The calcareous aspect of these samples was also reflected in the crystallitic b-fabric which can develop when calcite crystals precipitate the micromass, with pore space between soil grains filled by precipitated silt and clay size carbonate crystals of pedogenic

origin (Durand et al., 2010). As said before, $CaCO_3$ was present in form of mineral grains in the coarse fraction, due to the weathering of carbonate rocks fragments, but also as a secondary formation denoted by calcite hypocoatings and coatings.

A change appeared moving upwards along the sequence: samples BRE 8, BRE 7 and BRE 6 showed the disappearance of carbonates, a full decarbonation of sediments. They probably recorded the start of an environmental change, characterized by the regrowth of vegetation cover: the presence of limpid clay coatings (BRE 8) (Fig. 27, C and D), especially with sharp extinction lines, is usually associated with a final phase of clay illuviation and in condition of stable surfaces covered by vegetation (Deák et al., 2017). On the contrary, the sample BRE 7 showed layered, dusty and impure clay coatings and/or infillings probably corresponding to an early phase of illuviation, when waters (in this case as consequence of snow melt) with clay particles percolated in pores, drying as laminar flow along pore walls. In addition, dusty coatings are related to deforestation and anthropogenic activity. The dark and dusty appearance of these coatings reflected the presence of finely distributed organic matter (Kühn et al., 2010). Along with dusty clay coatings, another evidence that supported the hypothesis of deforestation and topsoil disturbance was the reorganization of sediments determined by the action of water on bare soils: already in the bottom part of BRE 8, which was characterized by an absence of peds, it was possible to localize these traces of splash erosion (Deák et al., 2017). Other traits of Holocene pedogenesis were the decarbonation of sediments (striated b-fabric), the development of soil structure (return to an angular to subangular blocky microstructure), and a markedly biogenic porosity (mainly channels, vughs and vesicles). This strong decarbonation is evidenced by the presence of a cross-striated b-fabric (BRE 8 and BRE 7).

The interpretation of the bottom part of the sequence can be fully understood by looking at the granulometry results (Fig. 25). The samples presented a high variability among themselves, in fact BRE 9 and BRE 7 showed different curves with respect to other samples of the sequence: those presented an almost flat curve, due to their poor sorting of aggregates. The materials presented in these samples are attributable to coarser morainic origin elements, indicated by more than 60% of sand with respect to a 30-45% in the other samples. This was enhanced by the already recognition in the field of the sample BRE 9 which represented a periglacial environment, a mean of transport that does not select the particles but carries on even large clasts, especially when its energy is very high. A clear difference is seen in samples BRE 6 and BRE 8, which showed steeper curves indicating better sorted sediments. Sample BRE 8 presented a distinctive amount of clay compared to all the other samples, with a percentage of about 20%, characteristic that was already visible in the field. In general, this group seemed to represent a high variety of granulometric range, from fine sands and clays (BRE 6 and BRE 8) to coarse granules (BRE 9 and BRE 7).

Other than on field observations, results from thin section analysis and granulometric data, the possibility to attribute this lower sequence to a passage from a glacial period to the pedogenesis activity which characterized the Holocene was also possible thanks to a radiocarbon date, coming from US 6, which localized the whole succession as prior to the second half of V Millennium cal. BCE. This time period comprised the Mesolithic, the Early Neolithic up to the full SMP culture period confirming the natural variation hypothesis, as climatic proxies for Northern Italy area in this stage showed an increase of temperatures and better climatic conditions suitable both for a soil development and human activities.

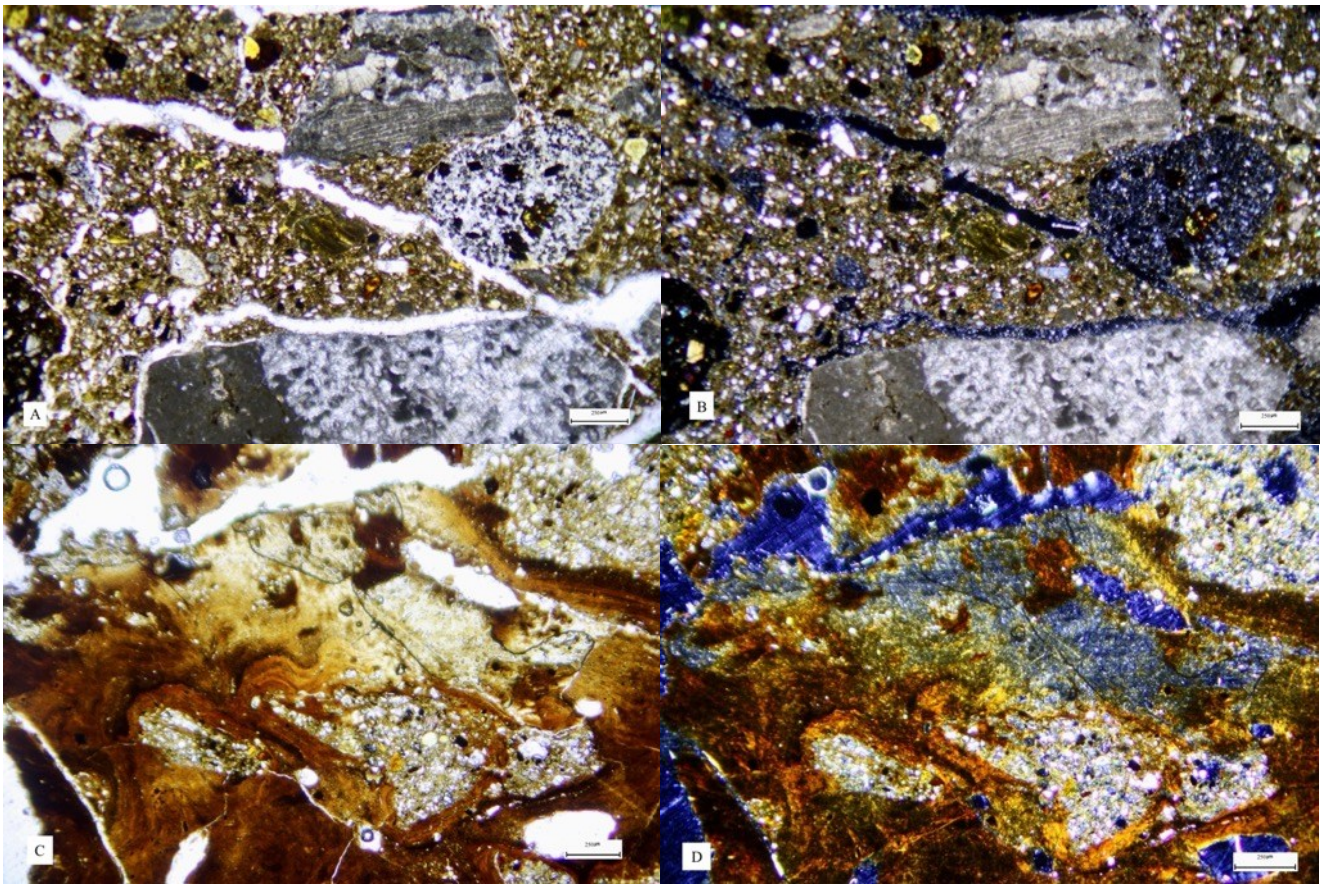


Figure 27 A: Examples of platy or lenticular microstructure (PPL) with carbonates and planar voids from sample BRE9. B: Same as A but in XPL. C: Examples of limpid clay coatings (PPL) from sample BRE8. D: Same as C but in XPL.

The second group to be discussed is the one considered as "black portion", which comprised samples BRE 5a, BRE 5b, BRE 4 and BRE 3. The name used to define it derived again from an observation on field: the dark colour characterizing the whole sequence. Within this group, as resulted from the analysis of thin sections, there were not many differences between samples.

Firstly, it is important to explain the reason why this sequence presented this dark colour. This, an overthickened A horizon, had an origin similar to that of Mollisols (Soil Survey Staff, 1975). These are characterized by a spongy fabric and humus from the disintegration and humification of organic residues carried out by faunal organisms. To the humification of vegetation there was a huge

contribution performed by animals, with earthworms and pot worms considered as the most important contributors to the soil biomass (Pawluk and Bal, 1985) indicated in these samples by the presence of channels. More specifically, it was possible to attribute this sequence to a subgroup of the Mollic class: this is the Cumulic subgroup, as the mollic or umbric epipedon reached great thicknesses (about 80 cm). Micromorphologically speaking, the main features representing this type of soil were denoted by vughs, channels and chambers (usually filled with little animal excrements), a homogenous groundmass with a close to single space porphyric coarse/fine related distribution pattern. Moreover, the organic material was exemplified in the groundmass by dark brown dots, indicating punctuations (Gerasimova and Lebedeva-Verba, 2010). In all these samples, these characteristics were present in a similar amount showing an elevated presence of punctuations, tissues and charcoals (Fig. 28, A and B) (percentages in Appendix A), and a porphyric c/f pattern. This sequence (particularly BRE 5a and BRE 5b) continued to present dusty clay coatings, although in a lower amount with respect to the previous series, indicating again bare soils determined by deforestation. Probably, these dusty clay coatings (Fig. 28, C) were the consequence of slaking events, or micro erosion, performed on the bare surface of the soil. Deforested soils are more fragile and undergo easier to the impact of rain drops. This absence of vegetation cover also determines the reduction of the infiltration capacity of the soil. A continuous action of slaking, micro erosions and streaming waters enhance other erosional phenomenon which destroy the sediments. This explosion as consequence to rainfall and erosion was the same process that happened in the previous sequence and probably was triggered again by deforestation. The presence of charcoal might have been the result of a deforestation performed by fire. In fact, plant eradication and deforestation performed through fires (slash-and-burn) are practices confirmed in many cases since prehistory and protohistory, and micromorphologically are attested by the presence of burned soil aggregates (BRE 4) (Fig. 28, D and E) and fine charcoal fragments. This latter characteristic is fundamental for the recognition of a deforestation performed by humans, which differs from a climatic one for the presence, in this case, of illuviation traces (Cremaschi, 2006). In this sequence, clay coatings were not dissimilar from the matrix, presenting more or less the same colour (Fig. 28, C), and became darker and darker approaching the sample BRE 4. The micromorphological analysis of the sequence ended with a colluvium (BRE 3), which originated over the soil but with the same characteristics: the events that determined the formation of the soil and that continued to feed it were the same of the ones that created the colluvium. In this case the amount of clay coatings or evidence of human activities were highly reduced, aspect demonstrated also on field during the excavation as little to no archaeological features were found.

Again, cumulative curves obtained from granulometric analysis (Fig. 26) seemed to confirm the similarity of these stratigraphic units. In fact, all the curves were comparable to one another,

indicating similar granulometric distributions and therefore more mixed but uniform materials, with the exception of samples BRE 4 and BRE 5a. Regarding the single curves, it was possible to determine that sample BRE 4 appeared as better sorted respect to the others, as the silt portion grew swiftly. On the contrary, sample BRE 5a was defined as the worst sorted, with a low amount of silt. The other curves, BRE 5b and BRE 6 (this latter present in both portions as the connection point of the two groups), were very similar with each other indicating a continuity in the stratigraphy. The soil's core of the A horizon, represented by samples BRE 6 and BRE 5b, showed an evident similarity with the colluvium (BRE 3 and BRE 2), indicated by the overlapping of their curves. This characteristic confirms two important aspects: firstly, the development of the soil started from the colluvial substratum, and not from the glacial substratum. The second feature confirmed by these analysis is the cumulic origin of the A horizon, derived from an input of formations. These accumulations deriving from colluvial processes, after 5.216-4.966 cal. BCE, might be connected to erosive phenomena on slopes induced by anthropic actions.

Considering radiocarbon dates, analysis performed on a charcoal fragment (14C-4) from BRE 5b indicated the end of the black sequence between 3.644-3.525 cal. BCE, a stage which slowly blended towards the end of the SMP culture and the end of the settlement. In fact, as already attested on field, the last anthropic evidence were present in the so-called sixth phase, corresponding to samples BRE 5a and BRE 4.

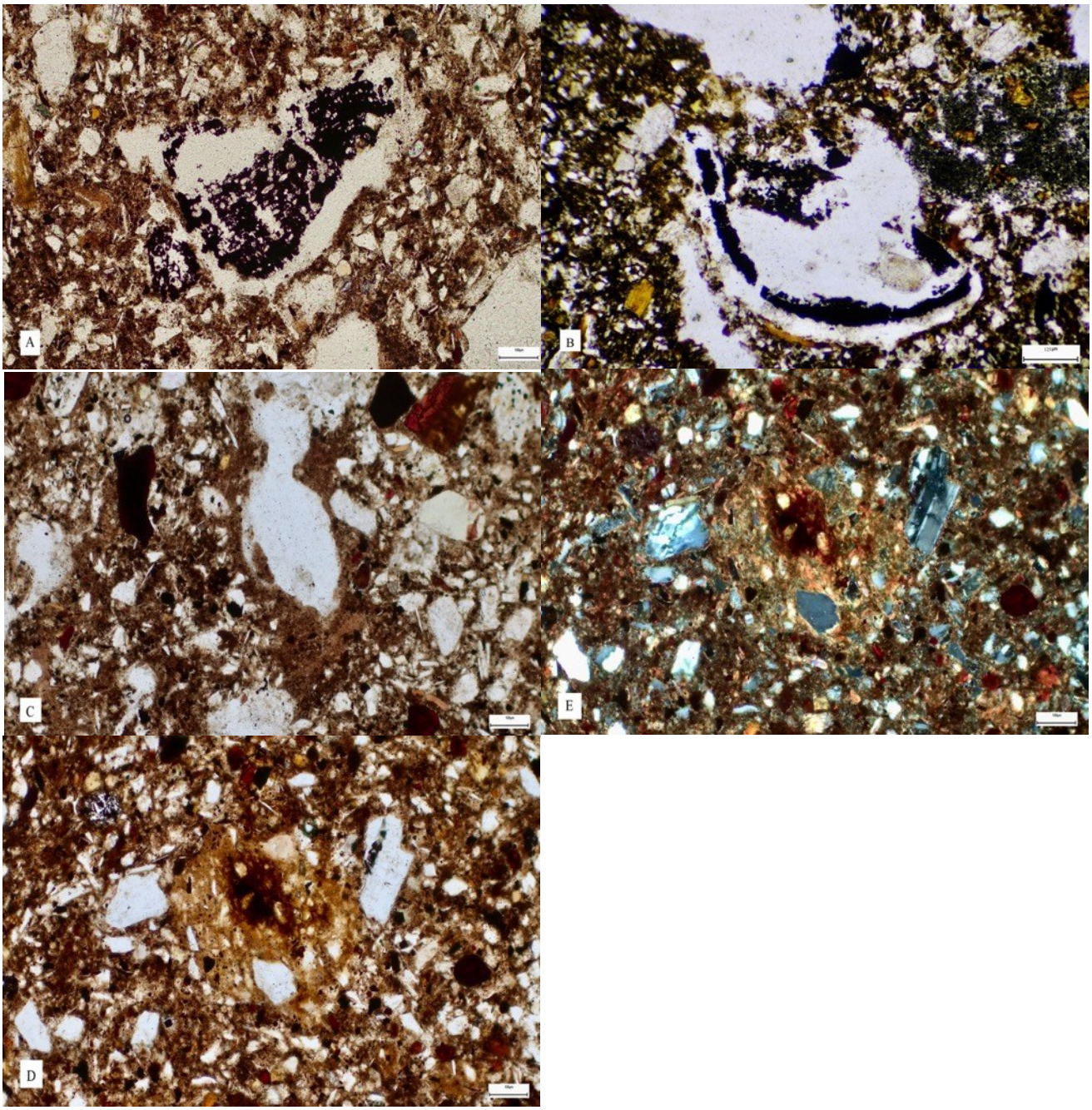


Figure 28 Example of a charcoal fragment within a dark fine matrix (PPL) from the sample BRE5b. B: Example of a tissue fragment In a dark matrix (PPL) from the sample BRE12. C: Dusty clay coatings, very similar to the fine matrix in colour (PPL) from the sample BRE4.

To summarize the situation presented here, it was possible to affirm that both thin sections and granulometry agreed with the preliminary subdivision of the stratigraphic sequence. The first group discussed, coming from the bottom part of the sequence, showed a great variation in sediments ranging from a soil characterized by periglacial activity (BRE 9) to a sediment showing traces of pedogenesis and anthropic impact (BRE 6). The presence of vegetation was represented by limpid coatings. but at the same time, there was also evidence of deforestation expressed by dusty and impure clay coatings presented in BRE 7, whom granulometry also returned to be slightly coarser. The real

change happened in between BRE 6, the dividing unit between the two groups: in fact, from this moment onward the site was fully inhabited, and a thick A horizon started to form. In this case the organic material and the fine sediments were prevailing, showing how different climatic conditions were, how the human actions allowed modifications on the surrounding environment and the presence of cumulic sediments of erosive origin. Specifically considering the texture triangle of soils (Fig. 29) of the single stratigraphic units, it was possible to further recognize the differences between those horizons who presented a coarser grain size (BRE 9 and BRE 7), and the ones which prevailed in fine sediments.

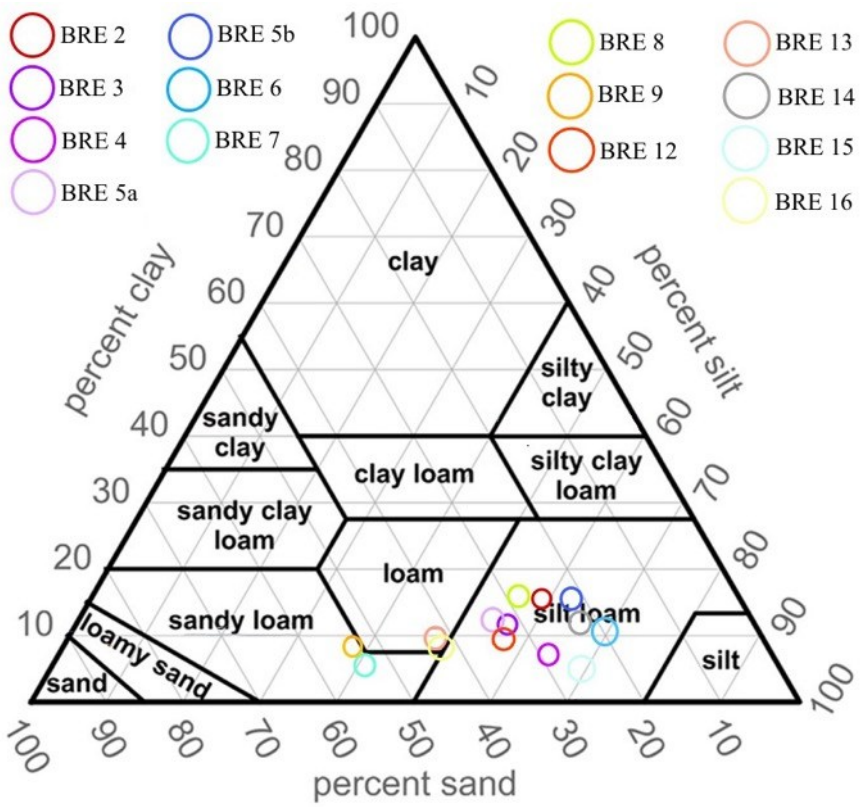


Figure 29 Texture triangle of soil showing the collocation of the samples within the scheme.

5. Conclusions

The gearchaeological research carried out on the site of Brentonico, in Trentino Alto-Adige region, allowed us to reconstruct in full the chronological sequence of the area. Through the analysis of samples collected in the field, a clear vision of the different events and their successions was exposed, so that this Neolithic site could have been located in the framework with other coeval and similar sites.

The exposed sequence presented two main unit groups, characterized by a different colour already visible in the field. Further analysis, such as micromorphological analysis, granulometry and radiocarbon dating, performed on samples coming from each stratigraphic unit of the groups allowed the recognition and identification of specific events which followed one another.

The red portion of the profile (cf. 3.1), corresponding to the lower part of the sequence, was identified as the base of the system over which the other strata and settlement developed. This part of the sequence showed different events: from the remnants of periglacial processes, the sequence developed with sediments characterized by the presence of a past vegetation cover, corresponding to a change in climate conditions, then destroyed by deforestation. Consequently, there were also traces of erosion, caused by the absence of vegetation cover which weakened the sediments. Moreover, the alternation of coarse and fine grain sizes and the presence of both poorly and well sorted sediments, other than the occurrence of limpid or dusty clay coatings indicated different processes which affected the soil allowing the characterization of the surrounding environment. These events were collocated in between a large temporal scale, passing from the Last Glacial Maximum (as evidenced by glacial heaves) to the full Neolithic, during the period of the SMP culture, about 4.674-4.453 cal. BCE (from the radiocarbon data of sample BRE 6). It was within sample BRE 6 that the passage from the red group to the upper part of the profile appeared: the transition was gradual, at least in the observation of the granulometry and the internal features presented in the thin section. In fact, the sediments placed at the border between these groups (BRE 6 and BRE 5b) did not present many differences neither in thin section nor in their granulometric curves, however the distinction was evident considering their colour.

The upper group (cf. 3.1), as a matter of fact, presented a homogeneous fine grain size and similar pedological features, and was recognized as part of a thick A horizon (named “black soil”) developed by the humification of organic matter and bioturbation in concomitance with human dwelling in the area. Again, there were evidence of deforestation, in this case probably performed by

humans (slash and burn) as burned sediments were found. The major characteristic of this group was its cumulic origin, probably derived from erosive processes started at the at the end of the VI Millennium BCE, indicated by the similarity between the units representing the core of the top part of the sequence (BRE 5b, BRE 5a and BRE 4) and the sediments identified as colluvium (BRE 3 and BRE 2). This latter group represented the final stages of the site as already in the sample BRE5b a radiocarbon date showed the final period of Neolithic (3.644-3.525 cal. BCE), concluded with colluvium at the beginning of the Copper Age.

Appendix A

Thin Section BRE 16
Porosity: Angular blocky, accommodated and moderately to highly separated. Inter-porosity characterized by channels. intra-pedal porosity presents planes and channels. **Microstructure:** Platy microstructure. **Coarse fraction:** Gravel <5%, coarse sand 20%, medium sand 10%, fine sand 15%, silt 10%, clay 35%. Sandy clay, poorly sorted and subrounded to subangular. Minerals: Clasts of carbonatic rocks with macroforaminifera as nummulites, discocyclina, red alges and bryozoans, probably from the Eogene-Oligocene. Micritic limestones with globigerinids, sponge spicules, globotruncana, and ostracods (Scaglia Rossa). Micritic limestones with calpionellids and radiolarians (Maiolica). Fragments of metamorphic rocks as microcrystalline granules of deformed quartz and gneiss with quartz, plagioclase and chlorine. Basalts with relatively coarse grain size, containing plagioclase, olivine, and devitrified glass. Clasts of highly altered, orange-coloured volcanic glass. Dikes or basic volcanic rocks with a high density of plagioclase phenocrysts in a dark matrix rich in Fe hydroxides and oxides. Volcanic rocks with olivine altered to iddingsite and pyroxene in a microcrystalline matrix rich in Fe oxides. Acidic volcanic rocks, light-coloured clasts with plagioclase phenocrysts in a microcrystalline light matrix (slightly pinkish in colour). **Organic fraction:** less than 5%, mainly punctuations. **B-fabric:** Crystallitic b-fabric. **C/f pattern:** Close porphyric. **Pedofeatures:** Very few impure clay coatings, absence of extinction lines, non-microlaminated to microlaminated. Few calcite coatings, typic, anhedral crystals parallel to the walls.

Profile 1, lower zone, Sez. 4. Thin Section BRE 9
Porosity: Angular blocky porosity, accommodated, and highly separated. Inter-pedal porosity characterized by planes. intra-pedal porosity characterized mainly by channels and few vughs. **Microstructure:** Platy microstructure. **Coarse fraction:** Gravel 15%, coarse sand 20%, medium sand 10%, fine sand 10%, silt <15%, clay 30%. Clay loam, moderately sorted, subrounded to subangular, smooth to undulating and with a medium degree of sphericity. **Minerals:** Clasts of carbonatic rocks with macroforaminifera as nummulites, discocyclina, red alges and bryozoans, probably from the Eogene-Oligocene. Micritic limestones with globigerinids, sponge spicules, globotruncana, and ostracods (Scaglia Rossa). Micritic limestones with calpionellids and radiolarians (Maiolica). Fragments of metamorphic rocks as microcrystalline granules of deformed quartz and gneiss with quartz, plagioclase and chlorine. Basalts with relatively coarse grain size, containing plagioclase, olivine, and devitrified glass. Clasts of highly altered orange-colored volcanic glass. Dikes or basic volcanic rocks with a high density of plagioclase phenocrysts in a dark matrix rich in Fe hydroxides and oxides. Volcanic rocks with olivine altered to iddingsite and pyroxene in a microcrystalline matrix rich in Fe oxides. Acidic volcanic rocks, light-coloured clasts with plagioclase phenocrysts in a microcrystalline light matrix (slightly pinkish in colour). **Organic fraction:** <5% of which >5% tissue size, >10% punctuations. **B-fabric:** Crystallitic b-fabric.

C/f pattern: Single spaced porphyric.
Pedofeatures: Few impure clay coatings, microlaminated, diffuse extinction lines.
Few infillings, loose continuous.
Few hypocoatings of calcite.

Profile 1, lower zone, Sez. 4. Thin Section BRE 8

Porosity: The upper part is characterized by a subangular blocky porosity, with channels and vughs concerning the inter-pedal porosity and few vughs regarding the intra-pedal porosity. Partially to unaccommodated and moderately separated. The lower part results apedal, but with vughs and channels as intra-pedal voids.
Microstructure: The upper part present a vughy microstructure, while the lower part is characterized by a massive microstructure.
Coarse fraction: Gravel 10%, coarse sand 10%, medium sand <15%, fine sand <15%, silt 15%, clay 40%. Clay loam moderately sorted and subrounded to subangular.
Minerals: Volcanic clasts similar to the ones present in BRE 9 (Basalts with relatively coarse grain size, containing plagioclase, olivine, and devitrified glass. Clasts of highly altered orange-colored volcanic glass. Dikes or basic volcanic rocks with a high density of plagioclase phenocrysts in a dark matrix rich in Fe hydroxides and oxides. Volcanic rocks with olivine altered to iddingsite and pyroxene in a microcrystalline matrix rich in Fe oxides. Acidic volcanic rocks, light-coloured clasts with plagioclase phenocrysts in a microcrystalline light matrix (slightly pinkish in colour)). Clasts of polycrystalline and deformed quartz, with quartz aggregates and rare muscovite along the metamorphic foliation. Non-deformed quartz, isolated magmatic crystals from granitoids.
Organic fraction: 5% of which 10% charcoal size, 15 tissue size, 15% punctuations. the majority of organic residues are to be found in the lower part of the thin section.
B-fabric: Grano-striated and cross-striated b-fabric.
C/f pattern: Single to double spaced porphyric.
Pedofeatures: Frequent impure clay coatings, compound layered/layered, diffuse extinction lines.
Frequent infillings, dense incomplete.

Profile 1, lower zone, Sez. 4. Thin Section BRE 7

Porosity: Angular blocky, partially accommodated to unaccommodated, and moderately to weakly separated. Inter-porosity characterized by channels and vughs. intra-pedal porosity mainly presents channels.
Microstructure: Channel microstructure.
Coarse fraction: Gravel <10%, coarse sand 15%, medium sand <10%, fine sand 10%, silt 20%, clay 30%.
Minerals: Similar to Bre 8, but with clasts of smaller dimensions: Clasts of polycrystalline and deformed quartz, with quartz aggregates and rare muscovite along the metamorphic foliation. Non-deformed quartz, isolated magmatic crystals from granitoids and gneiss with tourmaline. Many different volcanites as devitrification structures, basic volcanic rocks with plagioclase or with olivine altered to iddingsite. Acidic volcanic rocks, light-coloured clasts with plagioclase in a dark matrix rich in Fe.
Organic fraction: 5% of which 5% charcoal size, >10% tissue size, 15% punctuations.
B-fabric: Stipple-speckled and grano-striated b-fabric.
C/f pattern: Single-spaced porphyric.

Pedofeatures: Common dusty and limpid clay coatings, diffuse extinction lines, compound layers/microlaminated.
Frequent infillings, loose continuous.

Profile 1, lower zone, Sez. 4. Thin Section BRE 6

Porosity: Angular to subangular blocky porosity, accommodated to partially accommodated, and moderately separated**.** Inter-pedal porosity characterized by channels and planes mainly localized on the edges of the thin section, probably indicating peds bigger than the glass. Intra-pedal porosity presents frequent channels and common vughs**.**
Microstructure: Channel and vughy microstructure.
Coarse fraction: Gravel 3%, coarse sand 30%, medium sand 10%, fine sand 10%, silt 30%, clay 30%. Clay loam, moderately sorted, subangular and smooth.
Minerals: Basic volcanites among which coarse grain of basalt with plagioclase embedded in a dark matrix rich in Fe hydroxides and oxides, volcanites with olivine altered in iddingsite in a microcrystalline matrix rich in Fe oxides. Acidic volcanites, with light in colour clasts with phenocryst of plagioclase in a light microcrystalline matrix, bigger than in other units. Metamorphic rocks with biotite, quartz, fine grain muscovite (fill), in a lower amount.
Organic fraction: 7% of which about 10% charcoal size, 15% tissue size, <20% punctuations.
Anthropic fraction: Flint element, sharpened, one specimen.
B-fabric: Stipple-speckled b-fabric.
C/f pattern: Single spaced porphyric.
Pedofeatures: Few clay silt coatings, laminated and layered, diffuse extinction lines.
Common infillings, dense incomplete.

South profile, upper zone, Sez 2. Thin Section BRE 5b

Porosity: Angular blocky porosity, partially accommodated, and highly separated. Presence of only three visible peds, characterized by an inter-pedal porosity of channels and vughs. The intra-pedal porosity presents few channels and common vughs.
Microstructure: Vughy microstructure.
Coarse fraction: Gravel 5%, coarse sand <10%, medium sand <15%, fine sand 20%, silt 25%, clay 20%. Loam, moderately sorted, subangular and undulating.
Minerals: In the matrix there are fragments of quartz, muscovite, pyroxene and feldspar. Among the volcanites there are light and acidic rocks with plagioclase phenocrysts and quartz embedded in a cryptocrystalline and microcrystalline matrix. basic volcanites with olivine altered in iddingsite phenocrystals. Clasts of metamorphic rocks, as gneiss with quartz, plagioclase and quartz aggregates.
Organic fraction: 5% of which >5% charcoal size, >15% tissue size, <25% punctuations.
B-fabric: Stipple-speckled b-fabric.
C/f pattern: Close to single spaced porphyric.
Pedofeatures: Few dusty and impure clay coatings, non-laminated to microlaminated, diffuse extinction lines.
Very few infillings, dense incomplete.

South profile, upper zone, Section 2. Thin Section BRE 5a
Porosity: Angular to subangular blocky porosity, partially accommodated, and moderately separated, . Inter-pedal porosity characterized by channels and vughs. intra-pedal porosity with common vughs and few channels. **Microstructure:** Vughy microstructure. **Coarse fraction:** Gravel 10%, coarse sand <15%, medium sand 10%, fine sand 15%, silt 20%, clay 30%. Clay loam, moderately sorted, subrounded to subangular. **Minerals:** Acidic volcanites (with quartz characterized by corrosion pits) and basic volcanites with olivine altered into iddingsite, and a matrix characterized by microlites of plagioclase and a casual rotation. Riolites with phenocrysts of pyroxenes in a glassy matrix serpentine. intermediate volcanites embedded in a matrix with bigger grains and uniforms. Quartz crystals, angular, without deformations, and probably from granitoids. In the matrix there are many crystals of pyroxene, muscovite, rare opaque quartz and olivine transformed into iddingsite. **Organic fraction:** 5% of which <5% charcoal size, <15% tissue size, <20% punctuations. **B-fabric:** Stipple-speckled b-fabric. **C/f pattern:** Close to single spaced porphyric. **Pedofeatures:** Few impure clay coatings, microlaminated, absent to diffuse extinction lines. Few infillings, dense incomplete**.**

South profile, upper zone, Section 2. Thin Section BRE 4
Porosity: Subangular blocky porosity, partially accommodated, and moderately to highly separated. Inter-pedal porosity characterized mainly by channels, but vughs are present as well. intra-pedal porosity presents mainly vesicles and vughs. **Microstructure:** Complex microstructure of vesicles and vughs. **Coarse fraction:** Gravel 5%, coarse sand <15%, medium sand 10%, fine sand 10%, silt 20%, clay >35%. Clay loam, poorly sorted and subrounded to subangular. **Minerals:** Acidic volcanites embedded in a cryptocrystalline matrix, leading toward a pinkish colour. Basic volcanites with olivine altered into iddingsite. Granules of gneiss with deformed quartz, feldspar and muscovite. In the matrix there is quartz, plagioclase, muscovite, small lithic fragments of acidic volcanites, olivine transformed into iddingsite and granitoids. **Organic fraction:** 5% of which 10% charcoal size, <10% tissue size, <20% punctuations. **B-fabric:** Stipple-speckled b-fabric. **C/f pattern:** Single to double spaced porphyric. **Pedofeatures:** Frequent impure clay coatings, laminated, diffuse extinction lines. Infillings are also present, but they can be considered clay coatings given the partial filling of voids and their low impact over the overall pedofeatures.

South profile, upper zone, Section 2. Thin Section BRE 3
Porosity: Subangular blocky porosity, partially to unaccommodated, and moderately to weakly separated. Inter-pedal porosity characterized by channels and vughs. intra-pedal porosity presents common vughs and channels, and only few vesicles. **Microstructure:** Vughy microstructure. **Coarse fraction:** Gravel 10%, coarse sand 15%, medium sand 10%, fine sand 25%, silt <20%, clay 20%. Sandy clay loam, moderately sorted, subangular and smooth. **Minerals:** Acidic and basic volcanites. gneiss rich in quartz and muscovite with biotite. In the matrix there are quartz and muscovite. **Organic fraction:** 5% of which <5% charcoal size, 5% tissue size, >20% punctuations, one recognizable organ. **B-fabric:** Stipple-speckled b-fabric, and in some areas are present granostriations. **C/f pattern:** Single spaced porphyric. **Pedofeatures:** Common impure clay coatings, layered, absent to diffuse extinction lines. Few infillings, dense incomplete.

Section E-W, pyro-technological structure. Thin Section BRE 12
Porosity: Subangular blocky porosity with a weakly-developed pedalty, partially accommodated to unaccommodated. Inter-pedal porosity characterized by vughs and channels. intra-pedal porosity presents common channels and in a minor number of vughs and vesicles. **Microstructure:** Channel micromorphology. **Coarse fraction:** Gravel 10%, coarse sand 10%, medium sand 5%, fine sand 10%, silt 30%, clay 25%. Clay loam, moderately sorted, subrounded to subangular. **Minerals:** Acidic and basic volcanites, especially with olivine altered into iddingsite and rocks with a high density of phenocrystals of plagioclase in a dark matrix rich in Fe oxides and hydroxides. **Organic fraction:** 10% of which <15% charcoal size, <30% tissue size, about 30% punctuations. **B-fabric:** Stipple-speckled b-fabric. **C/f pattern:** Double spaced porphyric. **Pedofeatures:** Common dusty and impure clay coatings, microlaminated, diffuse to sharp extinction lines. Common infillings, dense complete.

Section E-W, pyro-technological structure. Thin Section BRE 11
Porosity: Subangular blocky porosity, partially accommodated, and weakly to moderately separated. Inter-pedal porosity characterized by channels and vughs. intra-pedal porosity mainly presents vughs, and in a minor amount channels. **Microstructure:** Vughy microstructure. **Coarse fraction:** Gravel 15% (in the lower part), coarse sand 15%, medium sand 10%, fine sand 15%, silt 15%, clay 25%. Loam, moderately sorted, subrounded to subangular, smooth and with a low degree of sphericity. **Minerals:** Acidic and basic volcanites, especially with olivine altered into iddingsite and rocks with a high density of phenocrystals of plagioclase in a dark matrix rich in Fe oxides and hydroxides. Metamorphic rocks as quartz in polycrystalline clasts, deformed, with quartz aggregates and muscovite. The rocks in this sample are in a higher amount with respect to the previous one and are all located in the lower part of the thin section.

Organic fraction: 10% of which 20% charcoal size, 30% tissue size, about 30% punctuations, very few recognizable organs (one specimen).
B-fabric: Stipple-speckled, but also grano-striated and poro-striated b-fabrics.
C/f pattern: Close to single spaced porphyric.
Pedofeatures: Common impure clay coatings, microlaminated, diffuse extinction lines.
Few infillings, dense discontinuous.

Appendix B

Sample	US	Section	Sand (63-2000)	Silt (4-63)	Clay (0-4)	Weight (gr) x> 2 mm	Weight (gr) 1<x<2 mm
BRE 2	3	Section 2	97,9	225,9	57,9	30,7	12,7
BRE 3	3	Section 2	94	173,9	34,6	12,9	11,5
BRE 4	4a	Section 2	105,5	228,5	20,4	38,5	12,2
BRE 5a	4b	Section 2	98,9	248,1	36,9	44,8	10,6
BRE 5b	4c	Section 2	89,5	268,1	61,9	39,5	9,4
BRE 6	20	Section 2	53,3	186,3	28,7	5,3	2
BRE 7	5	Section 4	178,2	135	20,4	47,8	28,8
BRE 8	6	Section 4	101,6	182,3	61,7	13,7	9,9
BRE 9	8	Section 4	226,5	156,7	32,5	76,3	40,8
BRE 12	191	Section E-W	100,9	166,6	32,1	27,9	8,5
BRE 13	314	Section E-W	170,8	188,6	37,5	59,3	23,5
BRE 14			41,7	120,6	20,7	14,1	2,3
BRE 15			49,7	136,6	11,4	27,1	2
BRE 16			71,5	83,8	11,9	31,5	11,8

Weight (gr) 710<x<1 mm	Weight (gr) 500<x<710	Weight (gr) 250<x<500	Weight (gr) 125<x<250	Weight (gr) 100<x<125
6	5,5	14,6	21,1	8,7
4,5	3,3	17	20	7,9
6,5	5,9	15,9	34,3	8,8
6,4	7,7	18	21,1	5
5,5	5,6	14,7	21,1	8,4
1,3	1,7	6,5	17,5	8,9
13,6	14,3	36,4	41,6	12,1
6,6	7,4	23,5	24	4,4
19,7	19,8	44,7	42,9	24
6,1	6,3	17,6	26,6	10,4
12,8	13	36	41,8	9,6
1	0,9	4,1	9,3	4,5
1,3	1,1	4,1	10,9	3,7
5,1	4,2	8,8	15,8	5,3

Weight (gr) 63<x<100	Weight (gr) x<63	Starting weight (gr)	Total sieving	Weight difference after organic digestion (gr)	% 2 mm	% 1<x<2
29,3	316,2	475,2	444,8	30,4	6,9	2,9
29,8	229,8	431,3	336,7	94,6	3,8	3,4
21,9	299,6	546,5	443,6	102,9	8,7	2,8
30,1	318,9	539,2	462,6	76,6	9,7	2,3
24,8	358,6	551,2	487,6	63,6	8,1	1,9
15,4	260,6	405,9	319,2	86,7	1,7	0,6
31,4	216,4	540,3	442,4	97,9	10,8	6,5
25,8	251	445,3	366,3	79	3,7	2,7
34,6	194,6	672	497,4	174,6	15,3	8,2
25,4	272,6	453,7	401,4	52,3	7	2,1
34,1	270,8	521,1	500,9	20,2	11,8	4,7
19,6	184,4	309,7	240,2	69,5	5,9	1,5
26,6	185,9	311,6	262,7	48,9	10,3	0,8
20,5	104,3	263,2	207,3	55,9	15,2	5,7

% 710<x<1	% 500<x<710	% 250<x<500	% 125<x<250	% 100<x<125	% 63<x<100	% <63
1,4	1,2	3,3	4,8	2,2	13,6	63,8
1,3	1	5,1	6,1	2,7	14,6	61,9
1,5	1,3	4,8	8,8	2,8	13,3	56,1
1,4	1,7	3,9	7	1,3	11,2	61,6
1,1	1,2	4,2	5,6	2,2	8	67,7
0,4	0,5	4,3	8,4	3,9	13	67,2
3,1	3,2	10,1	14,5	4,1	12,6	35,1
1,8	2	6,7	7,2	1,4	7,8	66,6
4	4	9	8,7	4,9	7,9	38,1
1,5	1,6	10	10,8	3,7	13,8	49,5
2,6	2,6	8,3	8,9	2,6	13,3	45,2
0,4	0,4	2,4	10,7	4	16,4	58,8
0,5	0,4	1,6	4,2	2,2	23,8	56,4
2,5	2	4,3	7,9	2,9	13,4	46,2

%gran (250-500) m	%gran (150-250) m	%gran (100-125) m	%gran (63-100) m	%gran (50-63) m
3,3	4,8	2,2	13,6	6,8
5,1	6,1	2,7	14,6	5,8
4,8	8,8	2,8	13,3	7,1
3,9	7	1,3	11,2	5,1
4,2	5,6	2,2	8	2,7
4,3	8,4	3,9	13	6,1
10,1	14,5	4,1	12,5	3,1
6,7	7,2	1,4	7,8	0,9
9	8,7	4,9	7,9	1,3
10	10,8	3,7	13,8	5,1
8,3	8,9	2,6	13,3	4,8
2,4	10,7	4	16,4	4,7
1,6	4,2	2,1	23,8	11,1
4,3	7,9	2,9	13,4	3,2

%gran (25-50) m	%gran (10-25) m	%gran (4-10) m	%gran (1-4) m	%gran (0-1) m	%250<x<500 gran su %x<63
22,4	11,6	10	10,6	2,4	84,38
21,9	13	10,9	9,2	1,1	85,35
23,9	14,1	6,4	4,3	0,3	81
20,1	18,2	10,2	6,4	1,6	81,09
14,4	21,2	16,8	11,7	1	83,47
21,1	18,7	12,5	8,3	1	92,5
10,4	10,2	6,8	4,5	0,1	66,28
9,3	19,7	19,9	16,1	0,8	83,07
9	12,3	8,9	6,3	0,3	59,5
15,1	12,1	9,2	6,1	1,9	77,81
13,9	10,2	8,8	6,2	1,2	70,01
16	17,3	12,2	8,2	0,5	89,99
27,5	8,1	5,3	3,6	0,7	86,45
13,7	14,6	9	5,6	0,2	70,35

%125<x<250 gran su %x<63	%100<x<125 gran su %x<63	%63<x<100 gran su %x<63	%50<x<63 gran su %x<63
79,57	77,39	63,82	57,01
79,29	76,57	61,94	56,12
72,21	69,39	56,07	49,01
74,13	72,8	61,59	56,51
77,87	75,72	67,68	65,02
84,15	80,21	67,23	61,12
51,83	47,69	35,13	32,02
75,84	74,44	66,64	65,77
50,84	45,93	38,05	36,71
67,02	63,29	49,52	44,41
61,09	58,48	45,15	40,33
79,25	75,22	58,83	54,14
82,25	80,1	56,35	45,3
62,45	59,56	46,21	43,01

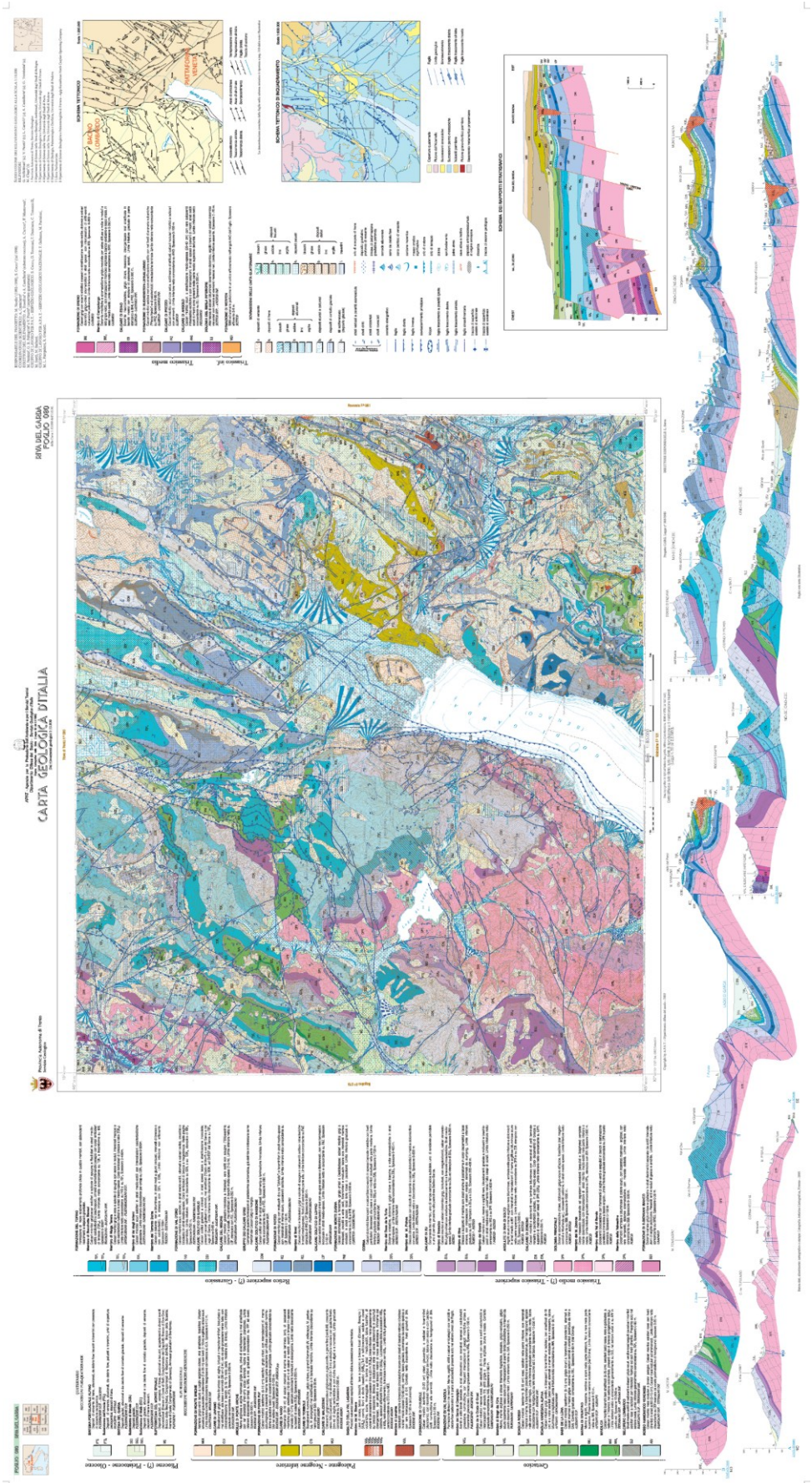
%25<x<50 gran su %x<63	%10<x<25 gran su %x<63	%4<x<10 gran su %x<63	%1<x<4 gran su %x<63
34,62	23,05	13,03	2,39
34,2	21,18	10,28	1,06
25,06	11,01	4,59	0,25
36,38	18,17	7,97	1,62
50,64	29,48	12,7	1,02
40,06	21,35	8,86	0,56
21,65	11,42	4,61	0,09
56,46	36,74	16,86	0,77
27,7	15,42	6,54	0,29
29,36	17,24	8,01	1,93
26,45	16,27	7,49	1,28
38,12	20,83	8,61	0,46
17,75	9,65	4,34	0,72
29,32	14,78	5,78	0,17

%0<x<1 gran su %x<63	%cumulative (x>2)	%cumulative (1<x<2)	%cumulative (710<x<1)	%cumulative (500<x<710)
0	6,9	9,76	11,11	12,34
0	3,83	7,25	8,58	9,56
0	8,68	11,43	12,89	14,22
0	9,68	11,98	13,36	15,02
0	8,1	10,03	11,16	12,31
0	1,66	2,29	2,69	3,23
0	10,8	17,31	20,39	23,62
0	3,74	6,44	8,24	10,26
0	15,34	23,54	27,5	31,48
0	6,95	9,07	10,59	12,16
0	11,84	16,53	19,09	21,68
0	5,87	6,83	7,24	7,62
0	10,32	11,08	11,57	11,99
0	15,2	20,89	23,35	25,38

%cumulative (250<x<500)	%cumulative (125<x<250)	%cumulative (106<x<125)	%cumulative (63<x<106)	%cumulative (50<x<63)
15,63	20,43	22,61	36,18	42,99
14,65	20,71	23,43	38,06	43,88
19	27,79	30,61	43,93	50,99
18,91	25,87	27,2	38,41	43,49
16,53	22,13	24,28	32,32	34,98
7,5	15,85	19,79	32,77	38,88
33,72	48,17	52,31	64,87	67,98
16,93	24,16	25,56	33,36	34,23
40,5	49,16	54,07	61,95	63,29
22,19	32,98	36,71	50,48	55,59
29,99	38,91	41,52	54,85	59,67
10,01	20,75	24,78	41,17	45,86
13,55	17,75	19,9	43,65	54,7
29,65	37,55	40,44	53,79	56,99

%cumulative (25<x<50)	%cumulative (10<x<25)	%cumulative (4<x<10)	%cumulative (1<x<4)	%cumulative (0<x<1)	Sample2
65,38	76,95	86,97	97,61	100	BRE 2
65,8	78,82	89,72	98,94	100	BRE 3
74,94	88,99	95,41	99,75	100	BRE 4
63,62	81,83	92,03	98,38	100	BRE 5a
49,36	70,52	87,3	98,98	100	BRE 5b
59,94	78,65	91,14	99,44	100	BRE 6
78,35	88,58	95,39	99,91	100	BRE 7
43,54	63,26	83,14	99,23	100	BRE 8
72,3	84,58	93,46	99,71	100	BRE 9
70,64	82,76	91,99	98,07	100	BRE 12
73,55	83,73	92,51	98,72	100	BRE 13
61,88	79,17	91,39	99,54	100	BRE 14
82,25	90,35	95,66	99,28	100	BRE 15
70,68	85,22	94,22	99,83	100	BRE 16

Appendix C



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