Chapter 6
A Digital and Archaeological Perspective of the World War One Veneto-Trentino Front Line Trench Systems in Northern Italy

Luigi Magnini, Giulia Rovera, Armando De Guio, and Giovanni Azzalin

Contents

Abstract Since the end of the First World War, material remains of the conflict have undergone progressive transformations. In the last decades, conflict archaeology has contributed to the investigation of these remains using a scientific approach.

We present the results of a comprehensive study of two Austro-Hungarian trench systems along the northern Italian Front, one located in the area of Millegrobbe, Trento, and the other, part of the Winterstellung in Rotzo, Vicenza. Our aim is to determine the conservation rate of the trench portions still present in the test sites and to investigate the natural and anthropic contributions in the processes of obliteration of the WWI infra(structures) and the restoration of the pre-war landscape.

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Methodologically, the study was carried out with different degrees of impact: noninvasive, remote sensing techniques (applied to both case studies) and (semi) automatic recognition of the visible war-related traces (only in Millegrobbe); field surveys to verify the reliability of the remotely sensed investigations and the preservation of the structures (both case studies); and microinvasive excavations (only for the Winterstellung) to identify the pre- sin- and postdepositional processes of natural and man-made origin that caused the heterogenous degree of preservation of the investigated structures.

Keywords First World War · Remote sensing · Formation processes · Archaeological survey · Object-based Image Analysis · Trenches

6.1 Introduction

The archaeology of the First World War (WWI) represents one of the most active and studied specialized domains (spatially, temporally, and functionally) within conflict archaeology. This interest has translated into numerous and different methodological approaches to the study of the First World War, in particular, those related to material culture (e.g., Saunders 2003, 2012; Schofield 2005; Saunders and Cornish 2014), archaeological excavations and surveys (e.g., Fraser and Brown 2007; De Guio and Betto 2008; Robertshaw and Kenyon 2008; Desfossés et al. 2009), physical anthropology (e.g., Hunter and Cox 2005; Le Bailly et al. 2012; Gaudio et al. 2013), geophysical prospecting (e.g., Doyle 1998; Masters and Stichelbaut 2009), and remote sensing (e.g., Stal et al. 2010; Gheyle et al. 2016; Mlekuž et al. 2016; Stichelbaut et al. 2016; Magnini et al. 2017a).

The use of archaeological methods and techniques is significantly changing the perspective from which WWI is perceived, not only as a chronicle of major events, global implications, or military tactics but also as a historic moment made up of countless small stories related to each social actor involved in the conflict. The landscape itself has become a central character, as it retains traces of the natural and man-made changes caused by the conflict and allows us to reconstruct in a diachronic perspective what preceded, what happened during, and what followed the war.

During the four years of conflict, both tactical and technical innovations strongly contributed to the formation of a new way of waging war which was continued during the Second World War. The wide range of these innovations, such as aerial fighting and trench warfare, had a considerable impact on the landscape. It is possible to follow this evolution using an archaeological approach, not only from the perspective of armaments but also from their impact on the landscape. In fact, the impact of the conflict has left deep scars still in “the healing phase” and created complex palimpsests of war-related traces still partially in incipient formation in the archaeological record. The study of the formation processes on the archaeological record of WWI represents a unique opportunity for studying, not only the natural and anthropic processes of modification/obliteration of contexts but also the mental processes underlying these changes.

The aim of this research is to study the entrenched system along the Alpine front line between the Kingdom of Italy and the Austro-Hungarian Empire using a multi-scale approach, and test a set of innovative methods derived from the most recent archaeological literature (Gheyle et al. 2018; de Matos-Machado et al. 2019; Van den Berghe et al. 2019). Specifically, our investigation focused on two areas: the first one is part of the entrenched system in the Millegrobbe area (Trento), involved in the war events in the first days of the conflict, and the second is part of the *Winterstellung* (Winter Position) defensive line, between the "Gibraltar" stronghold and the protohistoric site of the Bostel, in the municipality of Rotzo (Vicenza) (Fig. 6.1).

The study was carried out by adopting a three-step protocol to minimize time consumption, archaeological remains collection (no-collection policy), and warscape destruction (minimum tillage). Each of the three steps corresponds to an increased investigation scale and an increasingly invasive impact on the ground: whereas the analysis of small-scale remote sensing data causes no impact on the WWI remains, surface surveys and topographic mapping on a medium scale create a minimal impact. Finally, large-scale excavations or half-sections have a medium impact on the archaeological record.

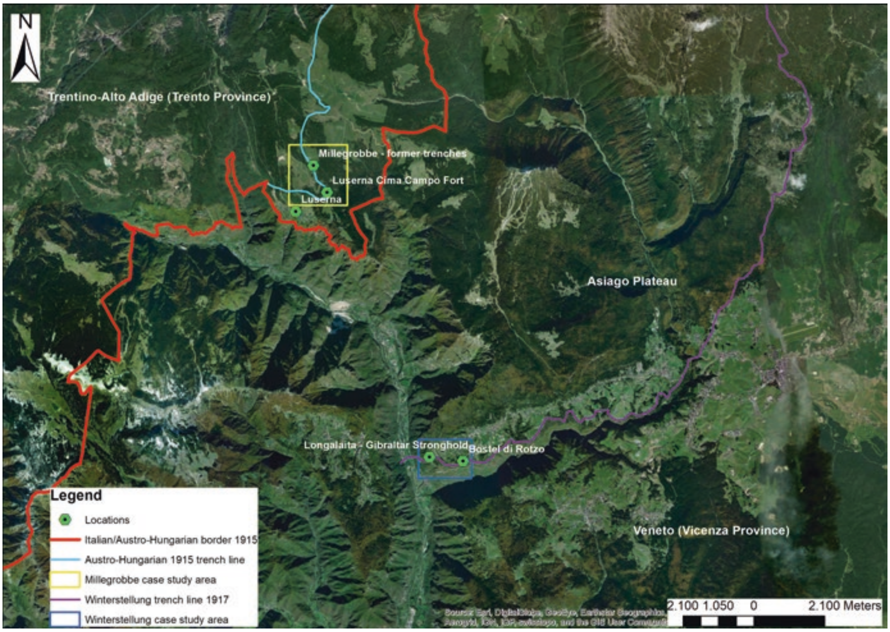

Fig. 6.1 Location of the study areas in Northern Italy

6.2 Archaeological and Historical Context

The front line between the Kingdom of Italy and the Austro-Hungarian Empire was mainly located in Alpine territory (at least from 1915 to 1917) (Fig. 6.1) and because of this, the war structures had to be adapted to the conformation of the terrain (Eliseo 2013). The Italian-Austro Hungarian border separates the Trentino-Alto Adige region from the Veneto region (Fig. 6.1), and here, both national armies had permanent fortresses in the valleys, on the plateaus, and in the mountain passes. In 1915, military operations focused mainly on overcoming these fortifications, and field attacks were almost completely excluded from the strategies of both armies.

The conflict between Italy and the Austro-Hungarian Empire officially began on 25th May 1915 in Luserna, when the Austro-Hungarian Luserna Cima Campo fort, known among the Italian troops as "the Almighty," and the nearby entrenched lines of Millegrobbe were attacked by Italian artillery with no less than 5000 shells fired in just three days. After initially collapsing, the Austro-Hungarian Army reorganized, and in the following months obtained more powerful artillery, e.g., the famous Škoda 305 mm and 420 mm siege howitzers, and managed to conquer first Verena fort, then Campolongo fort, and in a short time, most of the other Italian positions (Liber et al. 1988). Despite numerous battles, from that moment on, the positions of the two armies remained almost unchanged until the arrival of the first snow.

By 1916, the strategy had changed, and the biggest battle ever fought in the Italian mountains was launched by Austria's Chief of Staff, Conrad von Hötzendorf. *Operation Frühjahrsoffensive* (Spring Offensive), also called the *Strafexpedition* (Punitive Expedition), was a massive offensive against the Italian forces that lasted from 15 May 1916 to the end of June that same year. During the Strafexpedition, the Austro-Hungarian Army threatened to overrun the Venetian plain to the south (Thompson 2008). The operation took place on the plateaus and in the valleys of the Veneto and Trentino regions (Fig. 6.1). The first phase of the offensive was fast and effective, pushing the Italians to a defensive position on the southern edge of the Asiago Plateau (Fig. 6.1). There were direct battles between the two sides throughout the plateau, but in mid-June, the Italian Army managed to overwhelm the repeated Austro-Hungarian attacks and started their counteroffensive, slowly regaining ground (Acerbi 1992). The Austro-Hungarian forces retreated from their advanced positions and deployed on the Winterstellung, the defensive line they had started building during the initial stages of their advance. The Austro-Hungarian Army maintained this position until the end of the war in November 1918 (Offelli 2006). The Winterstellung was an important Austro-Hungarian defensive line built between 1916 and 1917. It is a defensive trench system that cuts across the Asiago Plateau, defining the new border between Italy and the territory conquered by the Austro-Hungarian Empire in 1916 (Fig. 6.1). It forms an uninterrupted line connecting fortified strongholds and other defensive systems to each other.

The Winterstellung represents an exceptional work that compensated for the complexity of mountain warfare. It is one of the most imposing defensive systems on the northern Italian Front. It holds a dominant position on mountain slopes and plateaus which facilitated observation of the enemy and was at the same time easily defensible (Vergara et al. 2019; Vergara and Bondesan 2020; Magnini and Bettineschi 2021). In addition, it was equipped with structures including trench lines, underground tunnels, cave shelters, emplacements, barracks, and the associated logistical support infrastructure (Balbi 2015). The trenches were about 1.5 m deep and were dug in either soil or the bedrock. They had ramparts about 50 cm high that consisted of soil sacks or drystone walls; the front trenches were protected by barbed wire and other obstacles. Because of its defensive strength and strategic position, the Italian troops never managed to break through the Winterstellung.

Trenches are one of the symbolic elements of WWI and are intrinsically linked to another war innovation of that period, intense shelling. The construction of kilometers of trenches and the subsequent shelling have indelibly marked the landscape. During the first months of the war, military commanders ordered the excavation of continuous trench lines for very large areas: for example, 760 km of trenches were built between the English Channel and the Swiss border (Keegan 1998). Often, the excavation of these structures during the initial stages of the war affected an already present and complex palimpsest of archaeological evidence, sometimes with devastating results, as in the case of the Winterstellung, where the trench that runs along the entire southeast side of the protohistoric site of Bostel di Rotzo has removed most of the archaeological structures present along the limits of the town (De Guio and Betto 2011a). In other cases, however, they helped to expose important stratigraphic windows that have been exploited for the study of otherwise undetectable buried contexts (De Guio and Betto 2005). The way the entrenched system looked varied according to the environmental conditions, the morphological features, the tools, and the time available to the troops for construction.

6.3 Applied Methods

The identification and study of both emergent and non-monumental war infrastructures (the so-called everyday life and death structures) and the material culture on the front line were carried out using noninvasive or microinvasive archaeological methods as noted above. Contemporary landscapes are characterized by a complex evolutionary process, whose palimpsestic traces can be extremely difficult to distinguish. Digital remote sensing techniques have intrinsic object/pattern/scenery recognition capabilities and an extremely high predictive and discriminatory potential that can improve the comparability of analytical data, reduce data processing times and avoid errors, and preconceptions that can influence classical archaeological photo interpretation (Halliday 2013). In this respect, machine learning techniques have had a very strong impact in recent years, not only in archaeological applications but in all areas of landscape analysis (Traviglia and Torsello 2017; Davis 2018).

A fundamental aspect of remote sensing recognition of archaeological traces is a solid understanding of the different types of structures and the possible formation processes (natural/anthropic and pre/sin/postdepositional) of the archaeological record (De Guio et al. 2015). Alongside these new remote sensing methodologies, it is important to maintain systematic control of the evidence identified both automatically and through traditional photo interpretation methods, especially in the field of archaeology. Above all, this is necessary because of the incompleteness of the archaeological record and the different formation processes underlying the surface traces (Schiffer 1972). Most of the interpretative issues related to remote sensing concern the equifinality[1] and multifinality[2] of the evidence and the seasonality of the data acquisition (Magnini and Bettineschi 2019). In fact, in many cases, as the seasons vary, the visibility of the traces can change, as does their type (e.g., negative or positive crop/vegetation marks). This aspect derives largely from the different use of the soil, the soil moisture, and the type of vegetation that allows identification of the buried structures (Magnini et al. 2019). For example, traces left by shelling are usually characterized by negative morphological anomalies with positive grass marks and low reflectance (Magnini et al. 2017a). However, in the case of anthropic interventions such as drainage remediations, diametrically opposite effects are induced with the almost total absence of negative morphological anomalies and above all, negative grass marks.

These specific aspects must also be taken into consideration during field surveys to validate the remotely sensed interpretation and to collect information about the location, distribution, and organization of WWI residual evidence (ground truth). Half-section digs, exposed stratigraphic windows, and micro-stratigraphic excavations were also fundamental to study the postdepositional impact of the war-related features after a century of pedogenetic processes (see e.g., Hupy and Shaetzl (2006, 2008) on 'bombturbation'). Half-section is a peculiar "then/now" excavation technique optimized for subsequent exposition (in terms of 'public archeology'). This procedure, based on the most recent theoretical-methodological trends, aims to present, not only to specialist users but also to a wider public, the most effectively illustrative models of an archaeological site in its formative and deformative manifestation (depositional and postdepositional processes). The technique consists, simply, in saving and leaving in its present state of abandonment a part of the deposit to return to the public three distinct and spectacular "information surfaces": (a) the excavated part (with original functional plans), (b) the part not excavated (abandonment), and (c) the connective interface between the two, that is, the stratigraphy (De Guio 2018).

[1] Equifinality accounts for similar morphogenetic outcomes derived from different archaeological entities at a certain point of their formation and transformation processes.

[2] Multifinality refers to all the possible morphogenetic outcomes of single archaeological entity, and is connected with the variability of the environmental contexts and the human-nature interactions which shaped that specific entity over the millennia.

6.4 Millegrobbe Case Study

The test area (Fig. 6.1), called "former trenches," extends from the road that leads to Malga Millegrobbe[3] to the wooded area east of the pastures. This location is characterized by a restored trench section and by the presence of numerous other trench sections that are partly buried, partly covered by trees, and partly visible, as well as by the strong presence of shell craters. Except for this example of selective and "memorialist" conservation, most of the structures have undergone a gradual process of obliteration due to natural causes in marginal areas not yet affected by urbanization, as well as anthropic ones especially in areas of high social and economic development. The different states of conservation of the trenches require a greater effort for mapping using (semi)automatic recognition methods (de Matos-Machado et al. 2019; Dolejš et al. 2020), and their study is even more demanding in the case where different portions of the same trench have very different residual characteristics.

Originally, these structures were long and narrow ditches dug into the ground with variable shapes (depending on the geomorphology, the nationality of the army, and the function), about 2 m deep and just as wide that extend from a few meters to several kilometers in length (Eliseo 2013). At present, however, these characteristics are only partially useful to effectively map this type of structure due to the postdepositional transformations mentioned above. Moreover, the presence in the test area of evidence with a high degree of equifinality/multifinality such as modern roads, paths, and mule tracks, requires an approach focused not only on morphological and formal characteristics but also on relational ones (Magnini and Bettineschi 2019).

6.4.1 Object-Based Image Analysis Classification

In this first study area, Object-Based Image Analysis, a very adaptable digital classification method, was applied to (semi)automatically identify the war-related features. The approach allows the creation of a specific and exportable rule set for each type of archaeological structure using textural, relational, spectral, and morphometric characteristics.

The most difficult part in the creation of a rule set for the trenches is addressing the different outcomes that a single archaeological structure can have. In order to overcome this issue, we adopted a three-step workflow that allowed us to explore the qualitative and quantitative classification potential of the method. First, we created a specific rule set for each different postdepositional outcome of the trench based on the conservation state visible on the images. Second, we carried out a field survey to verify the correspondence of each class with distinct formation processes

[3] 'Malga' in Italian is a complex of traditional alpine structures where animals and shepherds live during the summer months.

and the related state of conservation. And third, we merged the different classes into a single class to quantify the overall impact of the trench on the landscape.

Because of the dense woodland in the study area, the high resolution (1 × 1m) LIDAR-derived Digital Terrain Model (DTM) of the Autonomous Province of Trento was chosen for the landscape analysis. Four different DTM visualization techniques – the positive openness (Fig. 6.2a), the negative openness (Fig. 6.2b), the local relief model (LRM; Fig. 6.2c), and the sky-view factor (SVF; Fig. 6.2d) – have been applied to enhance and highlight the concave micromorphology, making it easier to identify specific archaeological objects such as the trenches (Kokalj and Hesse 2017; Burigana and Magnini 2018).

One of the most informative visualization techniques for delineating both concave and convex features from a digital model is "openness" (Doneus 2013). Openness is obtained using the mean of the zenith (positive openness) or the nadir (negative openness) angles along at least eight directions from each point of the model. The area affected by the algorithm calculation is defined by the user through the definition of a maximum search radius (Yokoyama et al. 2002).

The LRM increases the visibility of surface micromorphologies regardless of the angle of illumination by removing small-scale landscape morphologies. This model assumes that archaeological structures are generally characterized by a slight morphological discontinuity of a positive or negative nature (depending on the type of

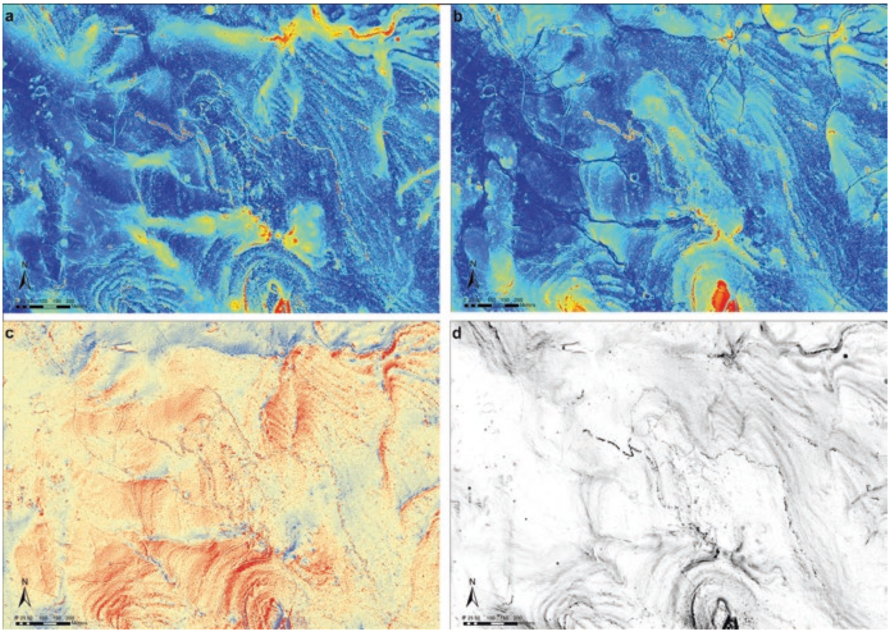

Fig. 6.2 Millegrobbe former trenches area (1.16 × 1.65 km). (**a**) Positive openness visualization of DTM with 1 m resolution. (**b**) Negative openness visualization of DTM with 1 m resolution. (**c**) LRM visualization of DTM with 1 m resolution. (**d**) SVF visualization of DTM with 1 m resolution. (DTM: Creative Commons License – Assignment 2.5 Italy) (http://creativecommons.org/licenses/by/2.5/it/legalcode))

evidence) with respect to the surrounding terrain. With the application of LRM, it is possible to overcome the problem of landscape morphology by extracting the small elevations on a local scale typical of the archaeological landscape (Hesse 2010).

Another very useful DEM enhancing technique is the Sky-view Factor. This method consists of quantifying the part of the sky that is visible at each point of the model. The computation is based on the vertical elevation angle of the horizon, the number of search directions (from 8 to 32 directions depending on the maximum search radius), and the maximum search radius (a large radius exposes large relief features, a small radius exposes more detailed features) (Zaksek et al. 2011).

The four visualization techniques of the DTM were then analyzed using an object-based approach which, following the first phase of segmentation, allowed objects of interest to be classified with a user-defined rule set. For the first phase, we applied a multi-resolution segmentation that, through a bottom-up approach, allowed a more accurate definition of the image-object with respect to geo-objects (or archaeo-objects in our case) by setting a scale parameter consistent with the size of the structures to be classified (Lang 2008; Magnini and Bettineschi 2019). Without going into the technical aspects of the rule set, the morphological characteristics of the trenches, already well highlighted by the four images, were used to classify the three different recognizable states of conservation of the trench (Fig. 6.3).

The first class (Fig. 6.3, yellow), located in the western part of the image in an area of open fields, has all the typical characteristics of the WWI trenches, and

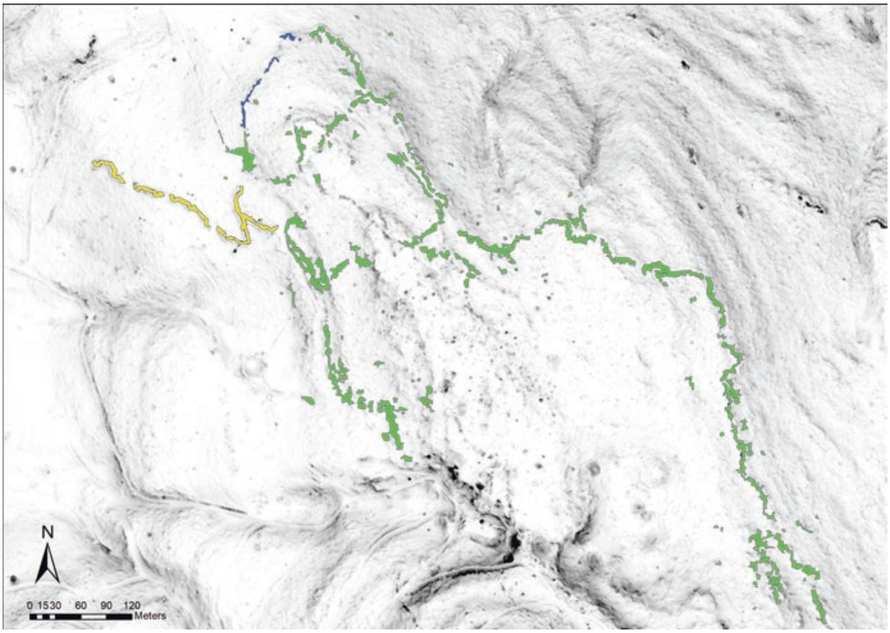

Fig. 6.3 Millegrobbe former trenches area. SVF visualization with object-based image analysis classification of the three different postdepositional outcomes of the trench. Yellow indicates the first class interpreted as restored trench; blue, the second class, interpreted as obliterated trench; and green, the third class, interpreted as abandoned trench

therefore, classification was quite easy. Less recognizable are the traces in the northern part of the area where the trench is barely perceptible in the images. Moving eastwards, where the vegetation begins, the visibility of the trench increases but is partial and fragmented. A specific rule set was created for each of these sections from some common features such as small dimensions and more or less slight depression of the ground. The second class (Fig. 6.3, blue) is limited to a short section in the northwest of the investigation area, connecting the first class with the third class which is covered by trees. Its regularity allowed us to make the best use of the length/width ratio to classify the traces visible on the DTM. The third class (Fig. 6.3, green), on the other hand, is characterized by a high degree of fragmentation that limits the continuity characteristics of the trench – there are more than 20 fragments in this class. Originally, it must have been a long, continuous structure that ran for several kilometers. Today, it appears to be subdivided into several segments that are generally close to each other. Although separated, the closeness of the segments to each other made it possible to recognize the trend and the direction. The rule set took this noncontinuous configuration into account, using the proximity relationship between the individual sections of the structure for classification.

6.4.2 Field Survey and Evaluation of Results

Following the (semi)automatic classification of the trenches, the test area was investigated through a systematic field survey to assess the reliability of the classification, as well as to discern the causes of the different postdepositional outcomes of the trenches. We also used the ground survey, which took place on 28 October 2018, to cross-validate the results and systematically monitored a large part of the trench route. Starting from the western portion of the trench, classified as first class and shown in yellow on Fig. 6.3, the survey followed the path of the trench first northwards and then, after turning east below the vegetation, checked the state of conservation of the structure in the forest. The field survey confirmed the presence of three different post-depositional outcomes for the same trench. The first class (Fig. 6.4a2, yellow) is the restored part of the trench (Fig. 6.4a1). It is very limited (200 m) and is located near the tourist routes.[4] It is the only portion that is clearly visible even on digital aerial photographs (De Guio et al. 2015) and preserves the morphological and dimensional characteristics typical of trenches that are also recognizable on the digital model.

The second class (Fig. 6.4b2, blue) identifies part of the trench that is almost completely obliterated (Fig. 6.4b1). This class is spatially limited (150 m) to the open field area and is in direct continuity with the restored portion. This segment has probably been subjected to voluntary anthropic obliteration, and only a small morphological difference in height that is barely large enough to be seen both on the

[4] There is a small road used during the summer by tourists for walking and cycling. Local people who have some economic activities in the area, such as pastures or timber exploitation, use this road, too. During the winter, it is part of a cross-country ski and dog sledge route.

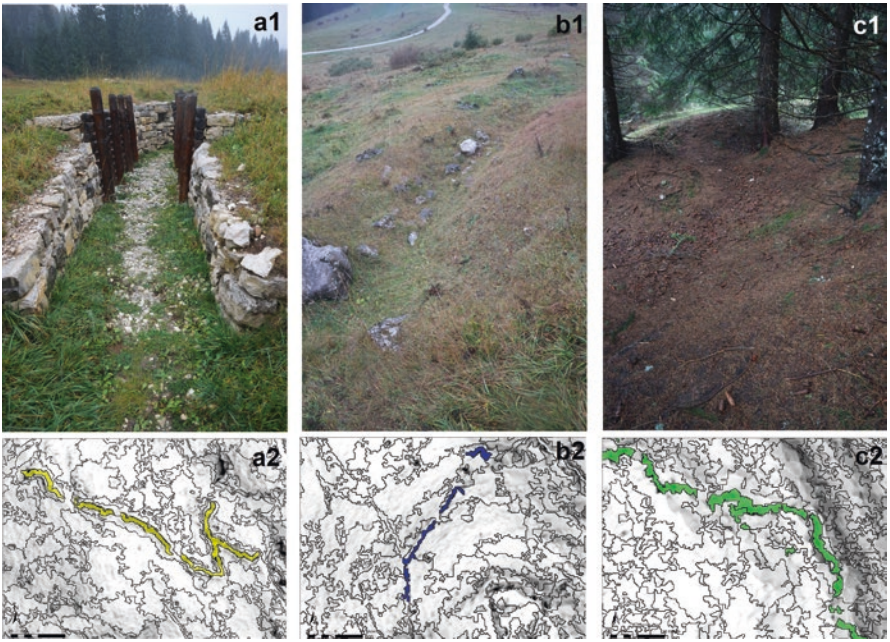

Fig. 6.4 Millegrobbe, former trenches area: comparison between the results of the semi-automatic classification (**a2**, **b2**, and **c2**) (300 × 210 m) and the ground-truth survey (**a1**, **b1**, and **c1**) of the trench. Each ground photo shows the actual state of preservation of each of the three classes. The ground images were taken in the areas shown on the corresponding classified image below. Yellow indicates the first class interpreted as restored trench; blue, the second class interpreted as obliterated trench; and green, the third class interpreted as abandoned trench

ground and the DTM is preserved. It is, therefore, possible to hypothesize, but not verify, that the first class should also have been in this condition before the restoration work.

The third class (Fig. 6.4c2, green) is entirely covered by not excessively dense vegetation (Fig. 6.4c1). It is the largest class and runs in two directions for a length of several kilometers. The first branch starts from the easternmost vertex of the restored trench and trends in a N/NW-S/SE direction. The second branch, trending NW-SE, begins at the northernmost point of the obliterated trench and extends along the entire eastern edge of the investigated area, taking advantage of the raised position. Both branches have the same morphological characteristics; they are only partially obliterated by natural processes and only the parts of the trench not affected by the presence of vegetation remain visible both on the ground and on the DTM. The interruptions are caused by the collapse of the walls of the trench and by the growth of vegetation on these collapses. In general, the trench parts of the third class have a shorter average length than the ones in the other two classes and are rather variable in-depth, ranging from 1.2 to 1.5 m.

Even in very diversified conditions, the reconnaissance effectiveness of LIDAR data in forest-covered areas, the specific visualization techniques to increase the visibility of morphological evidence, and the object-oriented approach have allowed rapid, effective mapping in this study area. This is in accordance with the diachronic semantic models proposed by the authors, minimizing bias and subjective interpretation errors.

6.5 The Winterstellung Case Study

The targeted analysis of this warscape was carried out in a limited area in the south-western part of the Asiago Plateau, specifically, in the municipality of Rotzo (Fig. 6.1, blue rectangle). This small village is located on the northern side of the Assa Valley, and, as a result of the Strafexpedition, was occupied by the Austro-Hungarian Army. The Italian forces were on the southern side of the valley. The study area was affected by events related to the Strafexpedition and thus, involved a pervasive anthropic impact in the mountainous landscape resulting from the establishment of a series of military infrastructures, the most important of which is the Winterstellung line (Stenghele 2010).

After years of conflict, the landscape changed considerably, but the scars of war were deeply impressed throughout this Alpine area. Local communities on the Asiago plateau, starting from the end of the war, began to deconstruct the mountains from the war system and some trench lines, emplacements, and shell craters were covered up to obliterate the signs left behind by the war (De Guio and Betto 2011b).

6.5.1 Remote Sensing and Cartographic Analysis

Much of the land is covered by the Winterstellung, which extends from Bostel, a protohistoric village to the Gibraltar stronghold (the western limit of the municipality of Rotzo; see Fig. 6.1), is thickly wooded. Unfortunately, a LIDAR-derived, high-resolution DTM, which would allow the ground to be "seen" through the trees, was not available and our interest, therefore, shifted to other types of data, such as time series digital aerial images and historical maps. It was only possible to carry out a partial analysis of the structures on aerial photography, so targeted field surveys including GPS mapping, with the double function of mapping the areas covered by vegetation and verifying the traces identified by remote sensing, were relied upon. GIS vectorizations of historical maps were used for cross-validation of the reliability of the image analysis and the GPS survey. Four military maps were used, three of which were British (updated on 24/06/1918, 22/08/1918, and 28/08/1918) and one, Austro-Hungarian (revised on 06/06/1918). The most recent one, the British map dated 28/08/1918 at a scale of 1:10,000, marked the course of the Winterstellung as it was known by the Italian and British Armies (Bondesan and Scroccaro 2017).

Table 6.1 The digital aerial images (Regione del Veneto – L.R. n. 28/76 Formazione della Carta Tecnica Regionale) used in the Winterstellung case study

Source	Year	Type of imagery	Resolution	Dimension in pixels
Reven Montagna Veneta	1982	Orthophoto	1.20 × 1.20 m	6078 × 6248
Reven Montagna Veneta	1991	Orthophoto	1 × 1 m	6223 × 5887
Reven Vicenza	2001	Orthophoto	1 × 1 m	6060 × 5769
Reven Asiago	2010	Orthophoto	0.17 × 0.17 m	6325 × 10742

The systematic analysis of time series digital aerial imagery captured between 1982 and 2010 (Table 6.1), highlighted some possible traces related to the Austro-Hungarian defense system. Analysis of the study area along the southern edge of the Bostel plateau identified part of the trench that unsettled the protohistoric stratigraphy (De Guio and Betto 2011a; Magnini et al. 2017b). On one hand, continuity with a structure previously excavated confirmed the interpretation and, on the other, served as a certain starting point for analysis of additional war-related features. On the west, there is another large area free of vegetation where there are numerous traces related to linear, meandering structures that follow the contours of the land and the limit of forest vegetation. Both the 1982 and 1991 (Fig. 6.5a) imagery confirm the presence of traces related to the passage of the trench for a total length of almost 400 m (Fig. 6.5b, red line); the 2010 imagery (Fig. 6.6a) shows in detail a section of just under 100 m where, thanks to the higher image resolution, it is possible to see the classic pattern of a trench (Fig. 6.6b, red line). A further stretch of the trench partially covered by vegetation, directly continuous with these latter traces, can be seen on the 1991 (Fig. 6.5b, red line) and 2010 (Fig. 6.6b, red line) imagery. In this case, the edge of the forest is interrupted close to a thin strip about 4–5 m wide without vegetation compatible with the morphological characteristics of a trench.

6.5.2 *Field Survey and GPS Mapping*

The field survey was carried out to identify the remaining traces of the Winterstellung structures and to track their conservation status. Ground truthing was also useful to verify the reliability of the remote sensing analysis. This noninvasive survey was combined with the use of a differential GPS Leica CS10 to acquire an accurate position of the trench line and to mark the positions of the main war features. The ground survey also led to the identification of five observation emplacements and 14 galleries (some with various internal branches) connected to the path of the trench line (Fig. 6.7).

The ground survey began at the site of Bostel di Rotzo (elevation 860 m) and extended to Longalaita, where the Gibraltar stronghold was built (elevation 720 m) (Fig. 6.7). This area is characterized by dense vegetation, soil cover, woods, and cliffs. The GPS equipment provided excellent accuracy in most of the area but was both inaccurate and of restricted use in wooded and rocky areas.

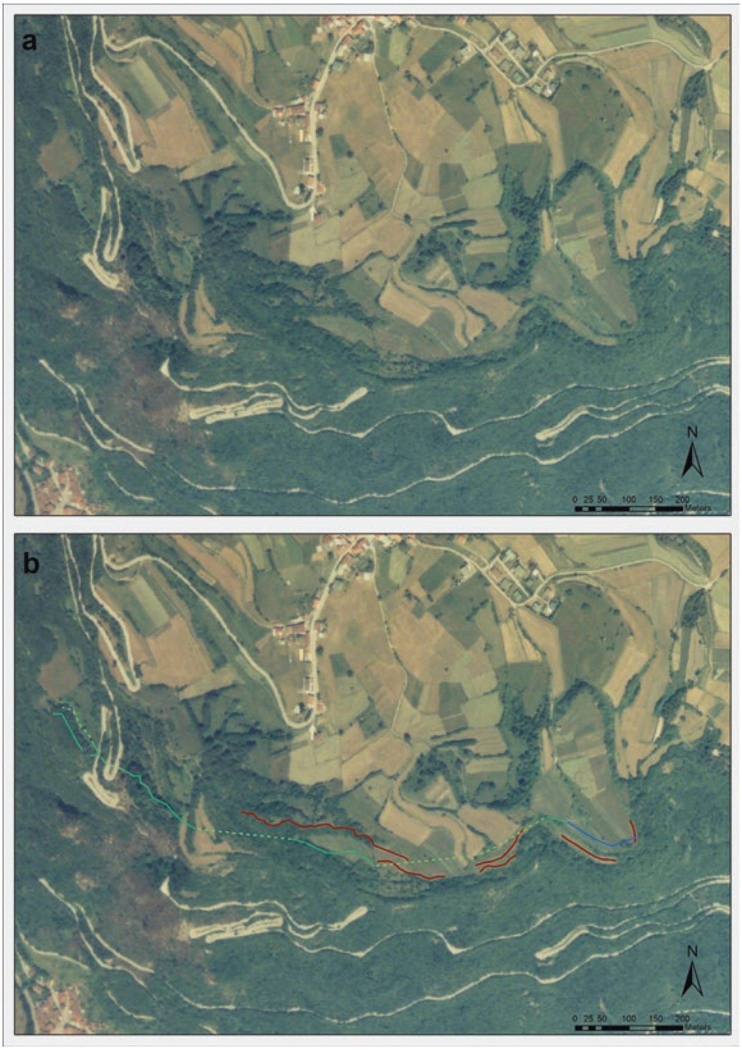

Fig. 6.5 (**a**) Orthophoto Reven flown in 1991. (**b**) The same air photo as (**a**) with trench traces identified by air photo interpretation (red). The dashed green line represents areas where no trench traces were identified during the ground survey and the dark green line, areas where trench traces were still visible during the ground survey. The blue line represents areas where trench traces were only partially visible during the ground survey

The survey revealed a wide range in the conservation status of the entrenched system shown in Fig. 6.7. Three general cases were identified: (1) Only in a few locations was it possible to positively identify the trench on the ground where it was only slightly obliterated and rather well preserved (Fig. 6.7, red line). (2) In other cases, it was still possible to follow the path of the Winterstellung line even though it was partially obliterated but still visible on the ground (Fig. 6.7, yellow line). (3)

Fig. 6.6 (**a**) Orthophoto Reven flown in 2010. (**b**) The same air photo as (**a**) with trench traces identified by air photo interpretation (red). The dashed green line represents areas where no trench traces were identified during the ground survey, and the dark green line, areas where trench traces were still visible during the ground survey

Lastly, in some places evidence of the entrenched line was completely lost and no longer visible on the ground (Fig. 6.7, dashed green line).

The heterogenous degrees of conservation and obliteration of the Winterstellung trenching system were ascribed to the different postdepositional processes that took place in the hundred years since the end of the war. In Case 1, the good state of conservation of the Winterstellung line is due to the particularly inaccessible positions of the trench (Fig. 6.8a). At one location, the trench was dug directly into the bedrock (Fig. 6.8b). In Case 2, the trench is only partially concealed, mostly due to natural factors such as small landslides or rock falls, which are typical of slopes in mountainous terrain (Fig. 6.8c and d). In Case 3, we were unable to identify the trench on the ground because it was completely buried by a combination of human actions and natural events: the processes of total obliteration of parts of the Winterstellung are in large part due to restoration of the pre-war landscape and fields by local communities, mainly for use as pasture.

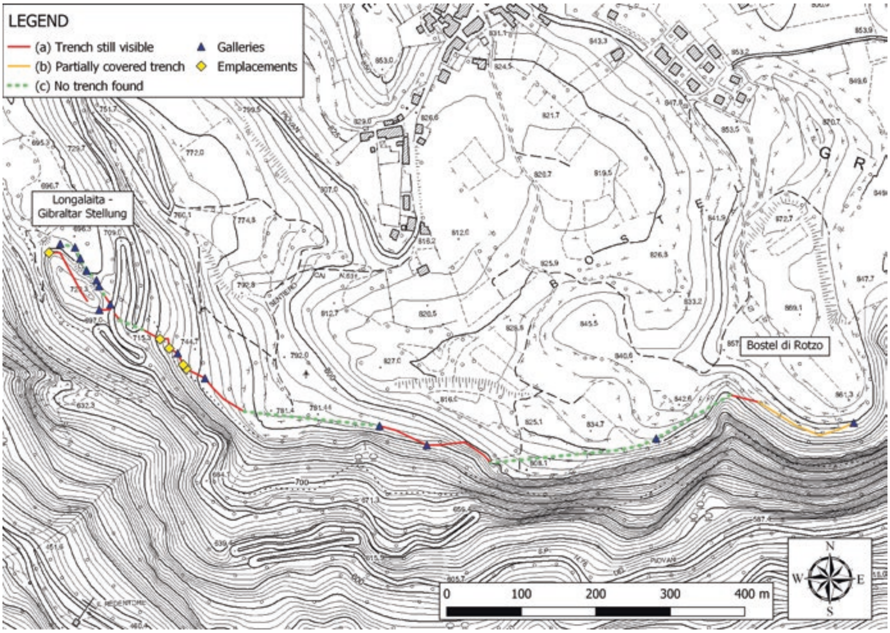

Fig. 6.7 GPS survey of the Winterstellung trench line. (Base map: Regione del Veneto – L.R. n. 28/76 Formazione della Carta Tecnica Regionale)

Fig. 6.8 Examples of trench remains along the Winterstellung line photographed during the ground survey. (**a**) Well-preserved trench, only slightly obliterated (case 1). (**b**) Trench dug directly into the bedrock showing a good state of conservation (case 1). (**c** and **d**) Trenches partially filled but still visible on the ground (case 2)

6.5.3 Archaeological Excavations

The analysis of the Winterstellung trench system also involved microinvasive archaeological excavation. This approach was used to examine the different post-abandonment dynamics that took place in two war infrastructures.

In the first instance, the archaeological dig, a stratigraphic excavation of a completely obliterated part of the entrenched line, only concerned a small segment of the trench line inside the Bostel di Rotzo Archaeological Site. This trench part had been identified by previous investigations in the area (De Guio et al. 2011). The excavation was carried out by digging a 4 × 4 m square in which the profile of the trench line and all the stages of filling that led to total obliteration and its leveling to the ground surface were identified (Fig. 6.9a). The results of the excavation were decidedly interesting, and led to the identification of several layers, some of which can be explained as the result of natural events (Fig. 6.9b, layer 909), whereas others appear due to anthropic actions aimed at obliterating the trench line (Fig. 6.9b, layers 902, 904, 905, 906, 907). The deeper layers (such as 906) were interpreted as the first phase of obliteration. They most likely consisted of the stone from the parapets that stood on both sides of the entrenched line. The operation of filling the entrenched line in the Bostel di Rotzo area was carried out with high accuracy, an indication of the will of the local community to get rid of the ground war traces. This was likely dictated by the economic needs of the post-war period that probably saw a return of agricultural activities to the area.

The second excavation adopted the half-section technique on an observation emplacement at the Austro-Hungarian Gibraltar stronghold (Fig. 6.7). This is a small hill overlooking all of the Astico Valley that was adapted as a stronghold through the construction of trenches, observation and machine-gun emplacements, galleries, and ammunition depots. It was readily identified during the ground survey because it was only partially obliterated. During WWI, this site became a fundamental Austro-Hungarian position from a strategic point of view thanks to its morphology: it controlled the confluence of the Assa and the Astico Valleys. Trenches on different levels were found in the Gibraltar stronghold, as were observation emplacements and many galleries with a complex system of internal junctions. The archaeological excavation only concerned the southern half of an emplacement and allowed the post-abandonment dynamics that led to a partial cover-up of the military infrastructure to be identified (Fig. 6.10a–c). The investigation revealed the almost total absence of archaeological stratigraphy and highlighted the boulder that closed the emplacement on the south in its entirety, revealing an embrasure in the lower part (Figs. 6.10b, d, 601). Another element detected, thanks to the excavation approach, was the bottom layer: this military feature was, in fact, excavated directly into the bedrock.

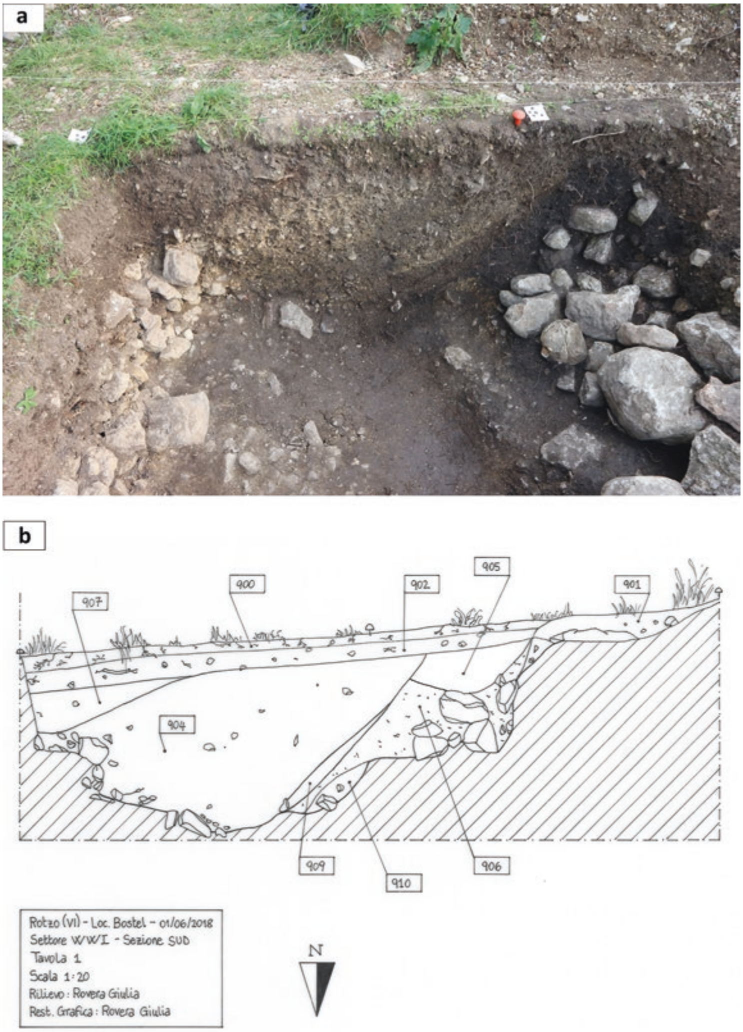

Fig. 6.9 (**a**) South section of the archaeological excavation that involved a completely obliterated Winterstellung trench section in the Bostel di Rotzo Archaeological Site. (**b**) The excavation has allowed the various phases of obliteration (due to natural events: 909; due to anthropic actions: 902, 904, 905, 906, 907) that led to a total cover-up of the trench in the post-war period to be highlighted

6.6 Conclusions

The two case studies confirmed that remote sensing analysis is the most effective small-scale investigation method for the study of the warscape even in partially wooded areas. In the Millegrobbe case study, it was possible to successfully map (semi)automatically more than 3 km of the trench using a combination of LIDAR-derived DTM visualization techniques and Object-based Image Analysis. This

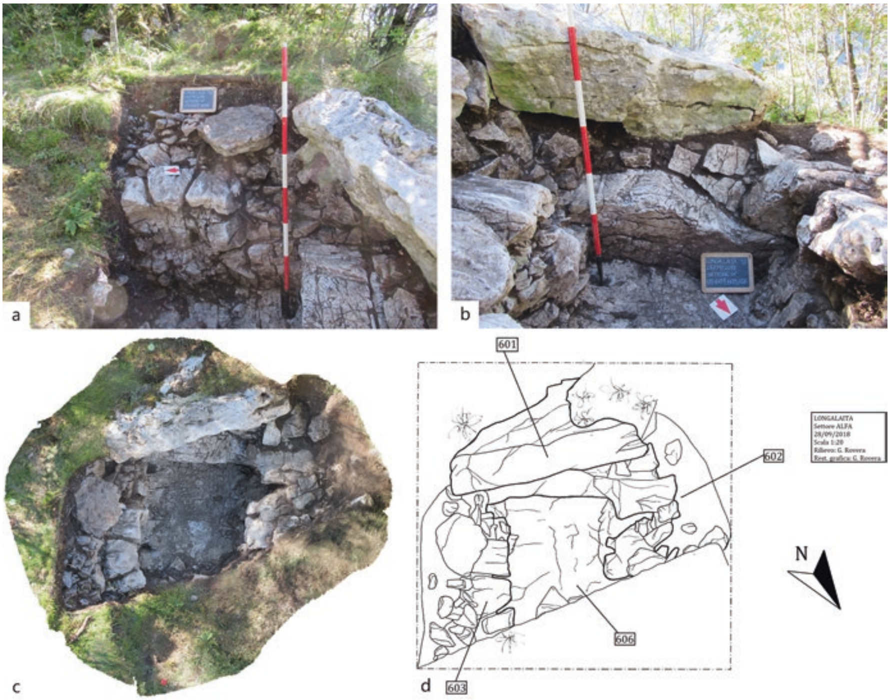

Fig. 6.10 Half-section of the emplacement in the Gibraltar stronghold. The trench was dug directly into the rocky surface, and the archaeological excavation revealed the post-abandonment natural dynamics that led to a partial coverup of the emplacement. (**a**) This image reveals the rampart of the military emplacement. (**b**) This image shows the boulder that closed the emplacement on the south section. (**c**) Orthophoto of the half-section. (**d**) Plan drawing of (**c**) at 1:20 scale indicating the archaeological layers

approach allowed us also to discern three different postdepositional outcomes of the original trench. This has been possible only by differentiating and adapting the semantic model of the trench to the different environmental and anthropic influences in context. The anthropic decision-making processes have also played a key role in the evolution of the trench formation and postdepositional processes. This is due to the different exploitation choices of the area in cognitive and functional perspectives, which are reflected in the recovery (Fig. 6.3, yellow), obliteration (Fig. 6.3, blue), and abandonment (Fig. 6.3, green) of the trench.

The subsequent ground survey confirmed the reliability of the rule set and of the interpretation. This application further demonstrates the potential of machine-learning techniques for the analysis of ancient landscapes if duly guided by a theoretical framework on the formation processes. In fact, without a diachronic semantic model derived from solid know-how of archaeological problems, the application of (semi)automatic recognition techniques would be strongly limited and decontextualized. In addition, these case studies further confirm that the assessment of the

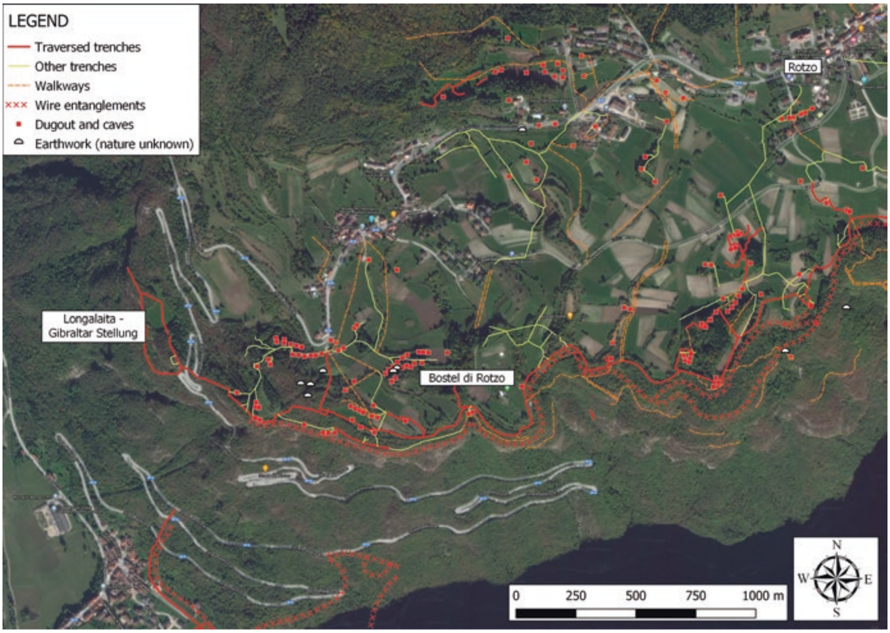

Fig. 6.11 Vectorization of the Winterstellung trenching system in the study area of Rotzo based on a British military map dated 28/08/1918 (Bondesan and Scroccaro 2017), overlain on a Google Hybrid satellite image. Details of the Austro-Hungarian trenching system found on the historical map are shown (see legend)

results of the (semi)automatic recognition is a key point in the workflow. In fact, automatic recognition procedures can only be improved through an accurate, ground-based analysis of the different outcomes of the formation processes that will provide new expert knowledge for future applications.

Almost 1 km of the trench was mapped with a differential GPS along the Winterstellung, and its reliability was verified through the combined use of remote sensing and historical maps (Fig. 6.11). The comparison between the results of our ground survey, the photo interpretation, and the British map confirms the high degree of accuracy of the topographic surveys during wartime. In fact, the traces identified and mapped by both GPS survey and remote sensing do not deviate significantly from the historical maps. Furthermore, through a systematic comparison of the trench on the British map with the traces left on the ground, it can be seen that much of the structural complexity of the defensive line is currently no longer visible or is in a precarious state of conservation. Although this allows archaeologists to study in detail the formation processes of structures in marginal and sparsely populated areas, it also leads to a significant impoverishment of the cultural heritage of one of the most important events of the twentieth century.

If LIDAR data had been available, however, the extent of the study area could have been enlarged: a LIDAR-derived high-resolution DTM would have allowed us to investigate those areas covered by trees (Crutchley and Crow 2010). The next step in the remote sensing analysis of the Millegrobbe trench system and the Winterstellung will be to acquire a new data set using an unmanned aerial vehicle (drone) with a thermal camera and a LIDAR sensor (Colombatti et al. 2017). Analysis of this data will allow the application of rule sets for the automatic identification of war-related features that have already been successfully tested at the Millegrobbe area (Magnini et al. 2017a; Magnini and Bettineschi 2019).

Thanks to stratigraphic excavations in different sectors along the trench in the Bostel di Rotzo area, we can confirm that the Austro-Hungarian trench has interfered with the layers resulting from the anthropic activities of the protohistoric village. The analysis of the stratigraphy also allowed the identification of various filling phases of the trench: nine different anthropic filling phases to obliterate and level up the war structure were identified. The applied methodology has also demonstrated the usefulness of the archaeological approach to study the heritage of the First World War: in fact, only through excavation and interpretation of the archaeological record, is it possible to clarify the phases of use of the site and the modalities of post-abandonment and obliteration. In this sense, the limited chronological gap that divides us from the use phases of the structure allows a greater understanding of the dynamics of abandonment and obliteration from an anthropic cognitive and decision-making perspective. In this case study (and more in general in contemporary archaeology), the cognitive approach allows us the possibility of understanding, not only the actions of the formation process but also why this process was done. For more ancient archaeological contexts, it is more difficult (but in some cases still possible) to understand the cognitive point of view of the human communities of the time.

The results obtained from the remote sensing analysis, the field survey, and the excavation of the Winterstellung trench line demonstrate the complexity and the importance of this defensive line for the Austro-Hungarian Army. The trench sections identified (and not excavated) during the survey comprise a massive structure: the construction of this entrenched system certainly required considerable Austro-Hungarian genius and effort, especially in inaccessible places like the slopes of the Astico Valley. Considering the above, the Winterstellung turns out to be a truly considerable work of military engineering which was to play a fundamental role in the Astro-Hungarian war strategy, especially considering the limited time for its construction.

In general terms, combining excavation, field survey, and the analysis of the remote sensing data, it was possible to outline a rather exhaustive picture of the obliteration dynamics (anthropic and natural) of the trenches in the investigated areas. These are largely attributed to natural processes in the case of partial or minimal filling of the structures located, in most cases, in wooded areas. On the contrary, the total obliterative processes are mainly assigned to human intervention and the need to return the land to agriculture and pasture.

The results of these scientific investigations will allow us to map the parts of the entrenched system that are still recognizable on the ground; this is fundamental to our goal of providing public access and guided tours of the local warscape in the future led by specialists in the field of conflict archaeology. The presence of experts will significantly improve the overall understanding of the "remaining warscape" and will stimulate reflections on the active role of every citizen in the protection of the WWI heritage.

References

Acerbi E (1992) Strafexpedition. Rossato, Valdagno

Balbi M (2015) La Grande Guerra e le montagne: soldati, alpinisti e alpinismo. In: Balbi M, Salvadori S, Giacomel P (eds) Il primo inverno in guerra. Kellermann jtane, Vittorio Veneto, p 18–33

Bondesan A, Scroccaro M (2017) Cartografia militare della Prima Guerra Mondiale. Cadore, Altopiani e Piave nelle carte topografiche austro-ungariche e italiane dell'Archivio di Stato di Firenze. Antiga Edizioni, Padova

Burigana L, Magnini L (2018) Image processing and analysis of radar and LIDAR data: new discoveries in Verona southern lowland (Italy). STAR Science and Technology of Archaeological Research 3:490–509

Colombatti G, Aboudan A, Bettanini C et al. (2017) Horus - a drone project for visual and IR imaging. 2017 IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace), Padova, p 589–592

Crutchley S, Crow P (2010) The light fantastic: using airborne laser scanning in archaeological survey. Historic England, Swindon

Davis DS (2018) Object-based image analysis: a review of developments and future directions of automated feature detection in landscape archaeology. Archaeological Prospection 26(2):155–163

De Guio A (2018) "Archeologia della Guerra": caro nonno ti scrivo… Aquileia Nostra LXXXVII (2016):11–42

De Guio A, Betto A (2005) Archaeology of the War, archaeology through the War: an analytical frontier in archaeological landscapes through digital technologies. In: Forte M (ed) Atti del II Workshop Italia-Stati Uniti. Roma, Italy, November 2003. Bar Publishing, Oxford, p 153–170

De Guio A, Betto A (2008) Archeologia della Guerra: nuove linee di ricerca. Archeologia della Grande Guerra 1:11–28

De Guio A, Betto A (2011a) Archeologia ed Etnoarcheologia della Guerra. Atti del 4° Convegno Nazionale di Etnoarcheologia, p 321–330

De Guio A, Betto A (2011b) Archaeology of the Great War: molto di nuovo dal Fronte Occidentale. In: Nicolis F, Ciurletti G, De Guio A (eds) Archeologia della Grande Guerra – Archaeology of the Great War. Atti del convegno internazionale di Archeologia della Guerra, Luserna, June 2006, Trento, p 143–176

De Guio A, Magnini L, Bettineschi C (2015) GeOBIA approaches to remote sensing of fossil landscapes: two case studies from Northern Italy. In: Traviglia A (ed) Across Space and Time. Papers from the 41st Conference on Computer Applications and Quantitative Methods in Archaeology, Perth, 25–28 March 2013. Amsterdam University Press, Amsterdam, p 45–53

De Guio A, Bressan C, Ferrari G et al. (2011) Bostel di Rotzo (VI) – stato di avanzamento delle ricerche. Quaderni di Archeologia del Veneto XXVII:168–183

de Matos-Machado R, Toumazet JP, Bergès JC et al. (2019) War landform mapping and classification on the Verdun battlefield (France) using airborne LIDAR and multivariate analysis. Earth Surface Processes and Landforms 44(7):1430–1448. https://doi.org/10.1002/esp.4586

Desfossés Y, Jaques A, Prilaux G (2009) Great War archaeology. Ouest-France, Rennes

Dolejš M, Samek V, Veselý M et al. (2020) Detecting World War II bombing relics in markedly transformed landscapes (city of Most, Czechia). Applied Geography 119. https://doi.org/10.1016/j.apgeog.2020.102225

Doneus M (2013) Openness as a visualization technique for interpretative mapping of airborne LIDAR derived digital terrain models. Remote Sensing 5:6427–6442
Doyle P (1998) Geology of the Western Front, 1914-1918. Geologist's Association Guides Issue 61. Geologist's Association, London
Eliseo S (2013) Le trincee quali fortificazioni campali durante la Grande Guerra. Rassegna dell'Esercito on-line 2, p 74–83. https://www.esercito.difesa.it/comunicazione/jtania/Rassegna-Esercito/Tutti-i-numeri/2013/Documents/n-2/rassEI_2_13_art_3.pdf
Fraser AH, Brown M (2007) Mud, blood and missing men: excavations at Serre, Somme, France. Journal of Conflict Archaeology 3(1):147–171
Gaudio D, Betto A, Vanin S et al. (2013) Excavation and study of skeletal remains from a World War I mass grave. International Journal of Osteoarchaeology 25(5):585–592
Gheyle W, Saey T, Van Hollebeeke Y et al. (2016) Historical aerial photography and multi-receiver EMI soil sensing, complementing techniques for the study of a Great War conflict landscape. Archaeological Prospection 23(3):149–164
Gheyle W, Stichelbaut B, Saey T et al. (2018) Scratching the surface of war. Airborne laser scans of the Great War conflict landscape in Flanders (Belgium). Applied Geography 90:55–68
Halliday S (2013) I walked, I saw, I surveyed, but what did I see? … and what did I survey? In: Opitz R, Cowley DC (eds) Interpreting archaeological topography: airborne laser scanning, 3D data and ground observation. Oxbow Books, Oxford, p 63–75
Hesse R (2010) LIDAR-derived Local Relief Models - a new tool for archaeological prospection. Archaeological Prospection 17(2):67–72
Hunter J, Cox M (2005) Forensic archaeology. Advances in theory and practice. Routledge, London
Hupy JP, Schaetzl RJ (2006) Introducing "bombturbation" a singular type of soil disturbance and mixing. Soil Science 171(11):823–836
Hupy JP, Schaetzl RJ (2008) Soil development on the WWI battlefield of Verdun, France. Geoderma 145(1):37–49
Keegan J (1998) The First World War. Hutchinson, London
Kokalj Z, Hesse R (2017) Airborne laser scanning raster data visualization: a guide to good practice. Založba ZRC, Ljubljana
Lang S (2008) Object-based image analysis for remote sensing applications: modeling reality - dealing with complexity. In: Blaschke T, Lang S, Hay GJ (eds) Object-based image analysis. Spatial concepts for knowledge-driven remote sensing applications. Springer, Berlin, p 3–28
Le Bailly M, Landolt M, Bouchet F (2012) First World War German soldier intestinal worms: An original study of a trench latrine in France. The Journal of Parasitology 98(6):1273–1275
Liber T, Leitempergher U, Kozlovic A (1988) 1914-18. La grande guerra sugli altipiani. Folgaria, Lavarone, Luserna, Vezzena, Sette Comuni, M. Pasubio, M. Cimone e sugli altri fronti di guerra. Rosato, Valdagno
Magnini L, Bettineschi C (2019) Theory and practice for an object-based approach in archaeological remote sensing. Journal of Archaeological Science 107:10–22
Magnini L, Bettineschi C (2021) Object-Based predictive modeling (OBPM) for archaeology: Finding control places in mountainous environments. Remote Sensing 13:1197
Magnini L, Bettineschi C, De Guio A (2017a) Object-based shell craters classification from LIDAR-derived sky-view factor. Archaeological Prospection 24:211–223
Magnini L, Bettineschi C, De Guio A (2017b) Il sito protostorico del Bostel di Rotzo: note di aggiornamento sugli scavi in corso. In: Deotto G, Bettineschi C, Magnini L et al. (eds) Progetto Horus: visioni dall'alto dello spazio archeologico. Padova University Press, Padova, p 13–19
Magnini L, Bettineschi C, De Guio A et al. (2019) Multisensor-multiscale approach in studying the proto-historic settlement of Bostel in northern Italy. Archeologia e Calcolatori 30:347–365
Masters P, Stichelbaut B (2009) From the air to beneath the soil – revealing and mapping Great War trenches at Ploegsteert (Comines-Warneton), Belgium. Archaeological Prospection 16(4):279–285
Mlekuž D, Košir U, Črešnar M (2016) Landscapes of death and suffering: archaeology of conflict landscapes of the upper Soča Valley, Slovenia. In: Stichelbaut B, Cowley D (eds) Conflict landscapes and archaeology from above. Ashgate, Farnham, p 127–146

Offelli S (2006) 1916 La spedizione punitiva. Rossato, Novale

Robertshaw A, Kenyon D (2008) Digging the trenches: the archaeology of the Western Front. Pen and Sword Military, Barnsley

Saunders NJ (2003) Trench art: materialities and memories of war. Berg, Oxford

Saunders NJ (ed) (2012) Beyond the dead horizon: studies in modern conflict archaeology. Oxbow Books, Oxford

Saunders NJ, Cornish P (eds) (2014) Contested objects: material memories of the Great War. Routledge, London

Schiffer MB (1972) Archaeological context and systemic context. American Antiquity 37:156–165

Schofield J (2005) Combat archaeology: material culture and modern conflict. Duckworth, London

Stal C, Bourgeois J, De Maeyer P, et al. (2010) Kemmelberg (Belgium) case study: comparison of DTM analysis methods for the detection of relicts from the First World War. Remote Sensing for Science, Education, and Natural and Cultural Heritage, Proceedings of the 30th EARSeL Symposium 2010, Paris, p 65–72

Stenghele D (2010) Storia fotografica: la Grande Guerra nella Valle dell'Astico, terra di Confine. Li, Velo d'Astico

Stichelbaut B, Gheyle W, Saey T et al. (2016) The First World War from above and below. Historical aerial photographs and mine craters in the Ypres Salient. Applied Geography 66:64–72

Thompson M (2008) The White War: life and death on the Italian Front 1915-1919. Basic Books, London

Traviglia, A, Torsello A (2017) Landscape pattern detection in archaeological remote sensing. Geosciences 7(4):128. https://doi.org/10.3390/geosciences7040128

Van den Berghe H, Gheyle W, Note N et al. (2019) Revealing the preservation of First World War shell hole landscapes based on a landscape change study and LIDAR. Geografisk Tidsskrift - Danish Journal of Geography 119(1):38–51

Vergara MN, Bondesan A (2020) The Cadore Offensive: theoretical military geography considerations. In: Guth PL (ed) Military geoscience. Bridging history to current operations. Springer Nature, Cham, Switzerland, p 67–83

Vergara MN, Bondesan A, Ferrarese F (2019) GIS analysis of the trafficability determined by slope in the eastern Tyrol front (WWI, Eastern Alps): a military history reading. Cartography and Geographic Information Science, 45(6):477–494

Yokoyama R, Sirasawa M, Pike RJ (2002) Visualizing topography by openness: A new application of image processing to digital elevation models. Photogrammetric Engineering and Remote Sensing 68:257–265

Zakšek K, Oštir K, Kokalj Z (2011) Sky-View Factor as a relief visualisation technique. Remote Sensing 3:398–415