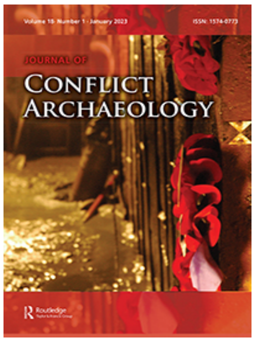

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A multidisciplinary scientific investigation of the 1916 Hawthorn Mine Crater, Beaumont Hamel, Somme, Northern France

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ABSTRACT

Hawthorn Crater is a prominent feature of the former Somme battlefield near Beaumont Hamel, Northern France. It resulted from the detonation of arguably the most famous of nine mines that the British had prepared below German lines on 1 July 1916, as part of the opening day of the Battle of the Somme. However, the crater has not been studied scientifically, as was in private land until recently taken over by the Hawthorn Crater Association. This paper documents three field seasons of multi-disciplinary site investigations. Methods included: remote sensing, drones, ground-based-LiDAR and surface surveys, geophysics and archaeological investigations. Magnetic anomalies were identified as: still-intact German fire pits, barbed wire and equipment, as the crater became the frontline after formation, and Allied shell craters. This study provided a rare opportunity to study a First World War mine crater, and highlighting modern science can assist detection and characterisation of significant archaeological sites.

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Introduction

The Battle of the Somme was one of the most significant and costly battles of the First World War. A Franco-British battle fought with Germany in northern France, the Somme was intended to be part of a co-ordinated Allied attempt to attack the Central Powers (specifically Germany and Austria-Hungary) on all Fronts. With the French under severe attack from the opening of the Verdun Offensive in February 1916, the battle would become, to a large part,

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British led. It commenced on 1 July 1916, and by its end, on 18 November 1916, some one million men had lost their lives (for overview, see Sheffield 2003; Prior and Wilson 2005).

The battle has achieved great cultural significance, associated as it has become with the introduction of the British volunteer citizen army – units of 'Pals' battalions amongst others – to a combat role, and the high level of combat losses experienced by them upon the first day of the conflict. Significantly, aspects of the battle was captured on film by official cinematographer Geoffrey Malins, who used both front-line footage and staged scenes to present a vision of the war that had never been seen before – and achieved a huge box-office success with *The Battle of the Somme*, shown before the battle was actually over (Hammond 2011; Malins 1920; Smither 1993; Todman 2014). An important part of this film was the explosion of the mine at Hawthorn Ridge, situated under a 'redoubt' or strong point in the German trench system. Malins's film of the explosion of the mine marking the start of the Battle of the Somme on NaN Invalid Date (Figure 1) is arguably one of the most significant pieces of combat footage ever filmed, and the significance of *The Battle of the Somme* is such that the film was added to the UNESCO *Memory of the World* register of cultural artefacts in 2005 (UNESCO 2005).

While most attention has been focussed on the effects of the explosion on 1 July 1916, the Hawthorn Ridge Crater actually comprises two large intercutting mine craters, with a deformed south-eastern edge, consistent with the explosion of two mines from the same gallery. The two large, intersecting depressions provide a record of these two explosions; a larger crater associated with the notoriously unsuccessful explosion carried out at 7.20 am on 1 July 1916 and a smaller crater associated with a much more successful explosion at 5.45 am on 13 November 1916, at the last stage of the Battle of the Somme – usually known as the Battle of Ancre. The resulting compound mine crater, privately owned and situated between other cultural assets within the Somme battlefields, the subject of this paper, has never before been studied in any depth.

Project aims were to document the first scientific multi-disciplinary site investigations of the Hawthorn Crater Redoubt. Study objectives were to; (1) provide background and

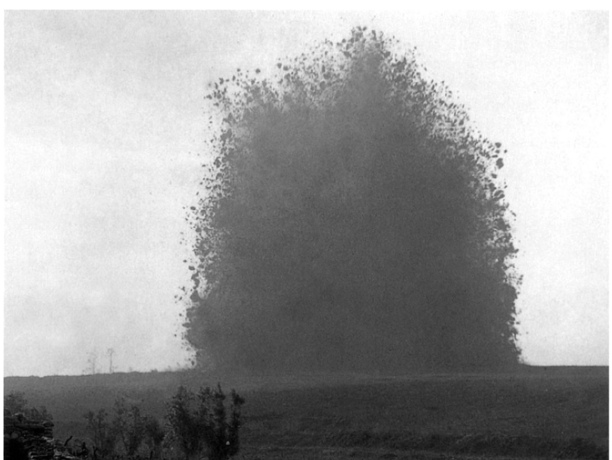

Figure 1. The explosion of the mine beneath the hawthorn ridge redoubt on 1st July 1916, as filmed by Geoffrey Malins (public domain).

existing information of the crater, (2) conduct careful non-intrusive modern site investigations, (3) conduct careful intrusive investigations to ground-truth results; and, (4) to determine the optimal site investigation techniques for others to use on other conflict archaeology sites.

Trench warfare and the Battle of the Somme, 1916

The First World War was fought across three continents and the major oceans of the world, although its principal theatres of war were situated within Europe (see Stevenson 2012, for an overview). Two main power blocks, the Allies or Entente Powers (principally France, Russia, Great Britain – joined later by Italy and USA) were arraigned against the Central Powers (principally Germany, Austria–Hungary and the Ottoman Empire).

In order to reduce the impact of the two-front war, the German strategy was to defeat France before Russia had time to fully engage on the Eastern Front, and as such enacted the Schlieffen Plan of 1905, which was intended to encircle Paris within days of invasion and destroy the French intent to carry on. Subject to modification and delay, the Schlieffen Plan never achieved its aims, and instead, led to the next phase of the war, the creation of the Western Front and the birth of trench warfare (e.g. Lloyd 2021; Stevenson 2012).

After some early battles of movement, when both sides attempted to turn each other's flanks, the front lines became relatively fixed, and from this point trench warfare became the norm. For the most part, similar trench systems were employed by the main protagonists on the Western Front. Fire trenches on both sides were usually arranged in successive parallel rows, with the front line, support line and reserve line all connected by the communication trenches, which were the main thoroughfares of trench warfare (Figure 2). As the war proceeded so trench warfare assumed complex proportions to give the maximum confidence of 'defence in depth' (Doyle 2014, 2017b, b).

In ideal circumstances, trenches were to be planned, laid out and traced across ground so as to take in natural characteristics and use them to advantage. The British Field Defences manual of 1908 recommended: 'The ideal site for trenches is one from which the best fire effect can be obtained, in combination with complete concealment of the trenches … As such positions will rarely be found, the best compromise must be sought for' (General Staff, War Office 1908, 48). For the German High Command, committed to ensuring their trench lines were the strongest, the use of natural features as strongpoints was the most important factor (*Stellungsbau*, translated by the General Staff, War Office 1917b), and consequently topographic features related to the underlying geology were used extensively.

> Great use has been made by the Germans of natural strong points, such as villages, farms, and woods. In the villages, the borders and interior have been strongly organised, generally for all round defence, and a particularly desperate resistance has been offered in them. The normal procedure, when taking up a new position, is to fix on a general line of natural strong points, and to prepare these for defence first and then to join them up by fire trenches, without much regard to the field of fire of the latter (General Staff, War Office 1917a, 17). This was certainly the case on the Somme.

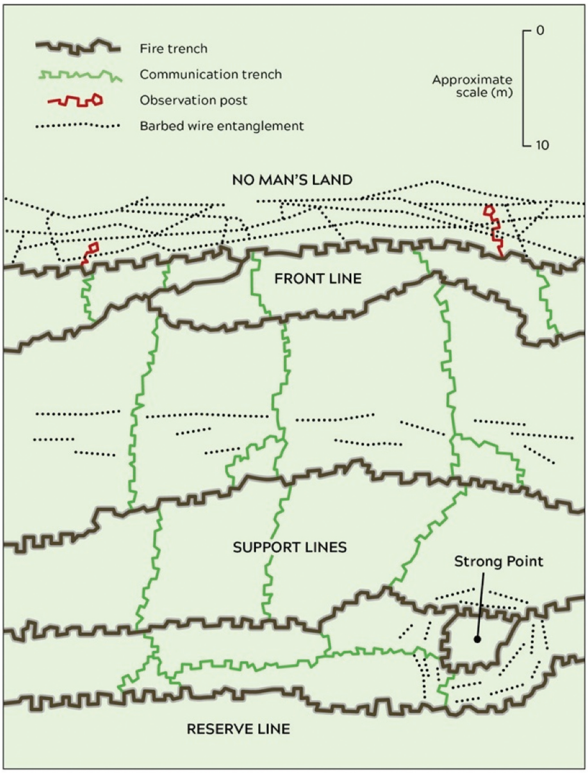

Figure 2. Schematic figure illustrating typical frontline trench warfare surface structures on the Western Front in 1916. Trenches are divided into forward-facing 'firebays' and rear-facing 'traverses' (modified from Doyle 2017a).

Geology and topography of the Somme

The chalk upland block of Artois and Picardy has a relatively simple structure, with a series northwest-southeast trending flexures creating the distinctive topography of the Somme, rolling chalk downland disturbed by woods and ravines (Figure 3).

The chalk of the Somme and Artois comprises three broad divisions: a lower, more clay-rich part (Coniacian age; *les marnes crayeuses*), a middle, flint-bearing level (Turonian – Coniacian age; *la craie grise à gros silex cornus*, overlain by *craie blanche à silex*), and an upper, pure white, flint-poor part (*craies blanche*) of Santonian – Campanian age (See *Carte Géologique de la France a 1/50,000, Albert XXIV-8*; see also Delattre et al. 1973; Doyle 1998, 2000, 2017a). The chalk is mostly frost shattered in its upper part. Other evidence of the Quaternary on the Somme is provided by the soil layers that lie above the white chalk, typically comprising four separate layers: clay with flints, loess, loam, and alluvium, although not all will be present at any given location. Wind-blown loess caps the clay-with-flints and is in turn covered by a clay-rich sand or loam (Figure 4). The loess and loam are often classified together on French maps as *Limons de Plateaux* – a fine covering on the upland areas, but sometimes reach a thickness of up to 10 m. It forms a cap to the hill-tops and slopes and helps to fill the valleys.

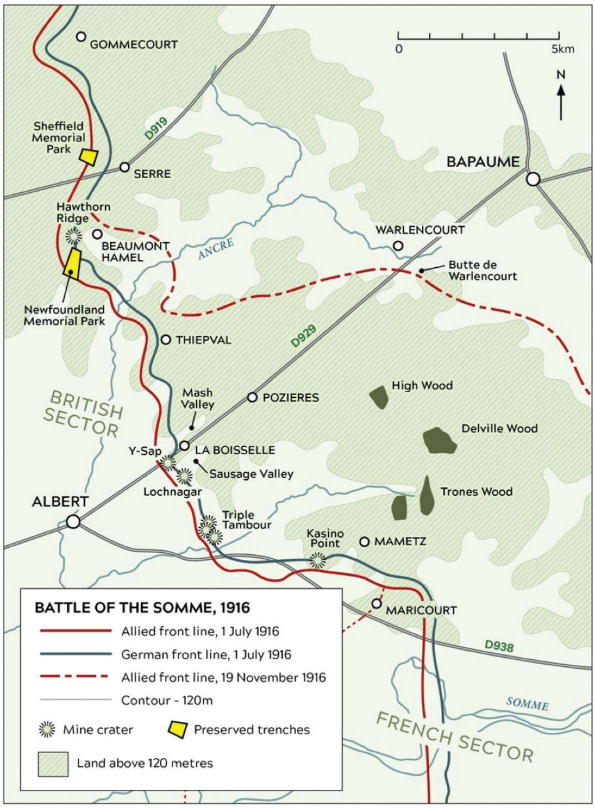

Figure 3. Topography of the Battle of the Somme in 1916. Note the underground offensive mine terminations marked by mine craters, with the Hawthorn ridge crater in the NW side of the map (modified from Doyle 2017a).

Natural topographic features, many of them a function of the chalk ground and its soil cover, were built into the German line on the Somme to great effect. The combination of ravines, spurs and woods became significant obstacles in 1916, as the Germans had exploited them in accordance with their 1916 military manual, *Stellungsbau*, translated by the British General Staff in 1917: 'Every suitable spot must be utilised for defence and be prepared beforehand for this purpose. Such places are called strongpoints (large, defended areas including villages, copses, etc, which may often be closed' (General Staff, War Office 1917a, 1–4).

Mine warfare and the Somme, 1916

With the establishment of trench warfare, it followed that military mining, the traditional approach to siege breaking, would be employed. In the First World War, the first attempts at breaking the siege through mining was developed in December 1914, with engineer companies waking to the need to destroy strong points, or to break the line through cratering at the surface (Boraston 1919, 189).

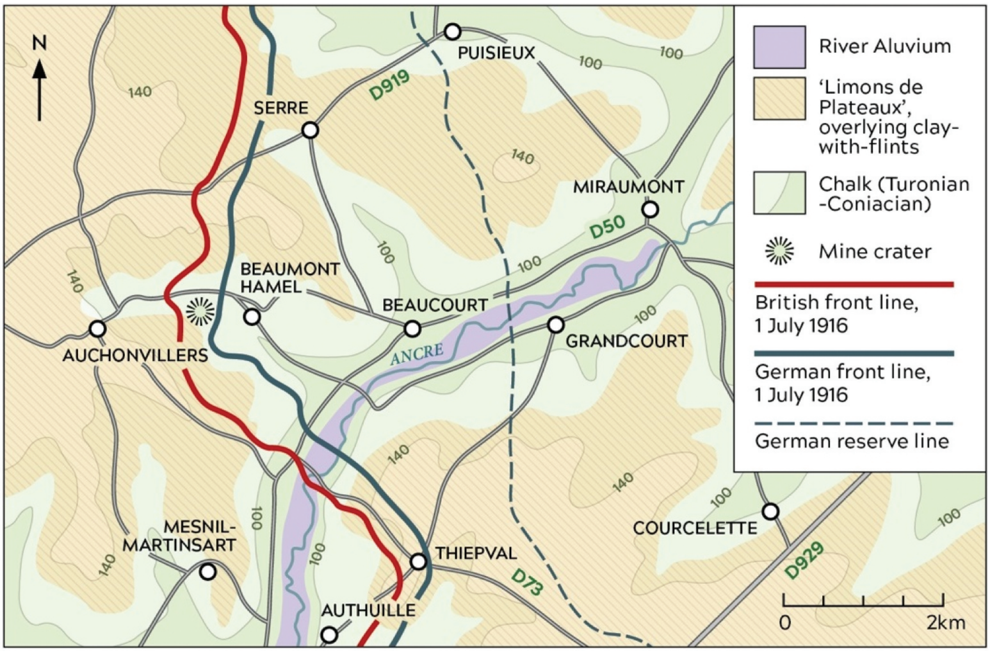

Figure 4. Geological map of the somme battlefield in 1916 (from Doyle 2017a).

Military mines are any underground system that was intended for offensive action through explosion, or indeed of defensive action to counter enemy mining. Throughout the war, from 1914 onwards, mining and tunnelling was carried out by specialist mining units on both sides with heavily fought over sectors in France and Flanders (See Kranz 1913, 1920, 1935; Füsslein 1921; Institution of Royal Engineers 1922; Grant Grieve and Newman 2009; von Bulow, Kranz, and Sonne 1938; Barrie 1961; Barton, Doyle, and Vandewalle 2004; Jones 2010; Willig 2011, 2016; Willig and Häusler 2012; Willig et al. 2015; Byledbal 2016; Doyle 2017a).

In France and Flanders, mining was inhibited by the nature of the chalk, clays and sands that determined the topography and landscape of the region. Surrounding Ypres, arguably the most successful mining was that which exploited the Ypres Clay, or of other clay layers that lay above it. It was in this medium that the approach known as 'clay-kicking', a specialist technique that allowed miners to work rapidly and silently, and drive galleries through the clay without recourse to picks and shovels. On the Somme, clay kicking was not possible in the chalk, miners used short-handled picks and shovels. Tunnelled galleries hewn with picks were self-supporting, with added timber being only necessary to prevent collapse of sections of roof through 'slabbing' (Ball 1919; Institution of Royal Engineers 1922; Grant Grieve and Newman 2009; Pennycuick 1965; Barton, Doyle, and Vandewalle 2004; Jones 2010; Doyle 2014, 2017a, 2017b).

The Allied Somme Offensive of 1916 saw the use of a coordinated effort to destroy strongpoints in the line through the use of deep offensive mines, together with a scheme of shallow tunnels, known as 'Russian saps' (Institution of Royal Engineers 1922; Grant Grieve and Newman 2009; Jones 2010) intended to provide cover for the attacking infantry, who would emerge from them into No Man's Land but were never used (Grant Grieve and Newman 2009, 135). Seven British tunnelling companies (174th, 178th, 179th, 181st, 185th and 252nd) were given orders to assist the offensive action by digging and laying nine large offensive mines (in addition a number of smaller charges) to destroy German strongpoints at Beaumont Hamel (Hawthorn Ridge), La Boisselle (Y Sap, Glory Hole, Lochnagar), Fricourt (Triple Tambour), Mametz (East and West) and Carnoy (Kasino Point) (Institution of Royal Engineers 1922; Grant Grieve and Newman 2009; Jones 2010).

The British miners in the main took over from the work of the French engineers, who had conducted mining operations against the Germans from at least 1915. At one location at least, a tract of land close to the village of La Boisselle known to the troops as 'The Glory Hole' there had been intense underground warfare that left the landscape so pitted with craters and filled with debris that it was mostly impassable (Jones 2010, 125). The galleries taken over by the British were at depths of around some 20–30 feet, and to avoid intersecting with the German workings, these were deepened to around 40 feet (Hance 1916; Jones 2010). In addition to the deep offensive mines, the Tunnelling Companies were also instructed to dig shallow 'Russian Saps' intended to provide cover for the attacking infantry, who would emerge from them into No Man's Land. Innovative approaches to softening the chalk was used here, with shallow augers dug through filled with water or even vinegar; this assisted the drive. But the Russian saps, so carefully planned, were never used (Grant Grieve and Newman 2009, 135). The offensive mine galleries were cut through the chalk at a relatively high rate – even though cutting through the mid-levels of the chalk they met much harder flint levels (Jones 2010, 116). For example, one gallery 4 ft 6 in high, 3 ft wide and 900 ft long was driven in 28 days again with mixed or limited results (Ball 1919, p. 216).

It was intended that each of the Somme mines would not only destroy the German strongpoints – but would be 'overcharged' with explosives, so as to create craters with pronounced lips that was huge compared with others, providing a 'temporary breastwork' for the attacking troops – if they could reach the crater first (Doyle 2017a; Grant Grieve and Newman 2009; Jones 2010). The General Staff gave implicit instructions that craters formed from the explosion of mines should be seized as quickly as possible, in order to be turned into such a strongpoint, with its upturned crater rim creating a considerable obstacle that would dominate the immediate area (General Staff, War Office 1916, 4). It was expected that the crater rim thus produced would be 'consolidated', with directions to excavate trenches in the forward lip (with firebays and traverses, see Figure 2), and with barbed wire and other obstacles placed to aid in the defence, while recognising that this represented a challenging task (General Staff, War Office 1916, 5–6).

The Hawthorn Redoubt Mine

As described by Jones (2010), the first mine at Hawthorn Ridge was intended to destroy a strong set of trench works, known as the Hawthorn Redoubt, that the Germans had constructed forward of the destroyed village of Beaumont Hamel (Figure 5).

These works were constructed on a chalk spur and as such, were especially significant and likely to be troublesome in any frontal assault. The gallery here was 80 feet deep and was dug by the 252 Tunnelling Company, commencing on 4 April 1916, and making good progress before hitting particularly flint-rich chalks that impeded progress. To avoid

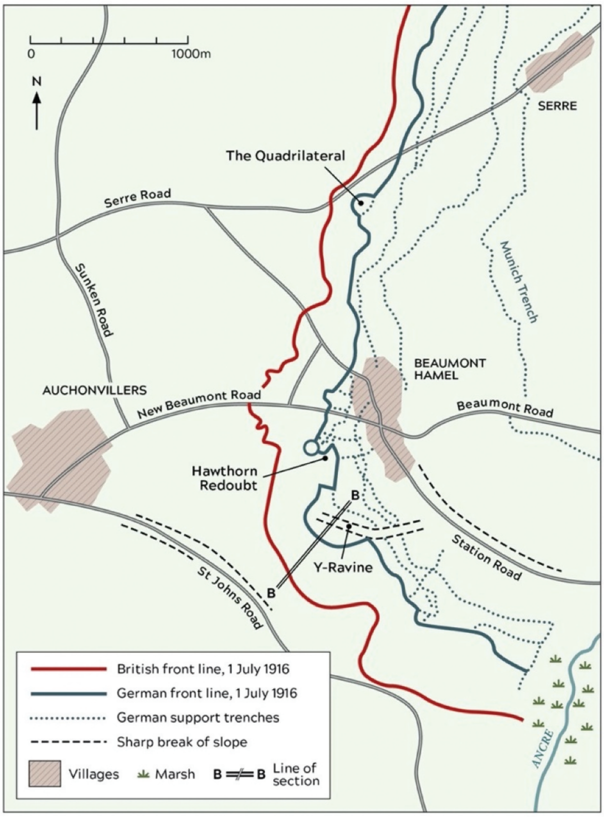

Figure 5. Location map of the Somme battlefield at Beaumont Hamel based on contemporary trench maps, and the location of the Hawthorn Redoubt Crater. See key for respective British and German front lines on 1st July 1916 (modified from Doyle 2017a).

excessive noise, the gallery (designated H3 on contemporary plans) was dug using bayonets working out chalk blocks softened by wetting, rather than by using picks (Jones 2010, 116). By 22 June, the mine was finished and some 40000lbs of the explosive ammonal was in place, an 'overcharged' mine which was designed to not only destroy the German surface works, but also to bury adjacent trenches with debris, and build up a lip that could be defended by the attackers (Jones 2010, 116). Concerns over the fall of these very debris would cause the explosion of the mine to be mishandled, leading to post-battle recriminations and a post-war investigation by the British Official Historian.

> 'Zero Hour' for the first day of the Battle of the Somme was set at 7.30 am on 1st July 1916; at this point, it was expected that the mines would be detonated to destroy the strong-points, that the infantry would advance to capture the craters, and that the artillery would support them by raining fire down on the German trenches in a series of 'lifts' (see Edmonds 1932; Prior and Wilson 2005; Sheffield 2003). While it might be expected that Hawthorn Redoubt mine would be fired at Zero Hour, thereby coming as a complete surprise to the Germans, it was actually exploded ten minutes in advance of Zero, an act that would have 'important and direful circumstances' (Edmonds 1932, 429), and which was described as a 'colossal blunder'. (Grant Grieve and Newman 2009, 124)

A careful analysis of why this decision was undertaken most recently by Jones (2010, 118–121). There was evidence to suggest that a case had been made by VIII Corps, whose sector on the Somme included Beaumont Hamel, for the mine to be exploded some four hours before Zero Hour – or even at 18.00 the previous day (Edmonds 1932, 429; Jones 2010, 115). But as this required the crater to be captured and held in No Man's Land, this was vetoed by GHQ (advised by Brigadier-General Harvey, The Inspector of Mines), as the British had never 'made a good show' at capturing craters in previous engagements, despite the explicit instructions given by the General Staff (Barton, Doyle, and Vandewalle 2004, 121–124; Edmonds 1932, 429; General Staff, War Office 1916, 4). Discussion then came down to the issues relating to the 'overcharging' of the mine, packing the mine gallery with sufficient explosive to through vast amounts of earth into the air, itself to act as a weapon; this was intended to bury the frontline trench with debris. According to Jones (2010, 118), the relevant commanders of the 29th Division – the infantry charged with attacking the front at Beaumont Hamel and ultimately taking Hawthorn Crater – were concerned that falling debris would be a serious risk to the soldiers if the mine was detonated exactly at Zero Hour. This was the first time such a huge mine had been detonated, and there was a distinct sense of reaching into the unknown. It was agreed that the mine should be detonated at 7.20 to give the earth time to settle. In fact, subsequent advice derived from the experience on the Somme that was issued in advance of the battle of Messines in 1917 indicated that the majority of blast debris would fall to ground some 30 s after detonation (Edmonds 1932, 430), and this was indeed the case.

Famously, Malins and recorded his feelings after the event: 'The ground where I stood gave a mighty convulsion, it rocked and swayed. I gripped hold of my tripod to steady myself. Then, for all the world like a gigantic sponge, the earth rose in the air to the height of hundreds of feet. Higher and higher it rose, and with a horrible, grinding roar the earth fell back upon itself, leaving in its place a mountain of smoke (Malins 1920, p. 142). The overcharged mine succeeded in destroying the Hawthorn Redoubt, garrisoned by Wurttemberg infantrymen of the 119th Reserve Infantry Regiment (Gerster 1920), who reported that:

> More than three sections of No 9 Company were blown into the air and the neighbouring dugouts were broken in and blocked. The ground all round was white with the debris of chalk as if it had been snowing, and a gigantic crater, over fifty yards in diameter and some sixty feet deep, gaped like an open wound in the side of the hill'. (Gerster 1920, quoted by; Edmonds 1932, 431)

The Hawthorn Ridge Redoubt Crater

Though the explosion had achieved this part of its aim, it was a failure. The early explosion had alerted the Germans that the infantry attack was imminent, and the formation of the crater (Figure 6) provided the defending troops with an opportunity to re-create a strongpoint in their line farther out in No Man's Land – something the British had hoped to do in their attack (Figure 7).

On explosion, two platoons of soldiers from 'Z' Company, 2nd Royal Fusiliers rushed forwards to capture the crater as instructed – but the 'enemy forestalled them on the

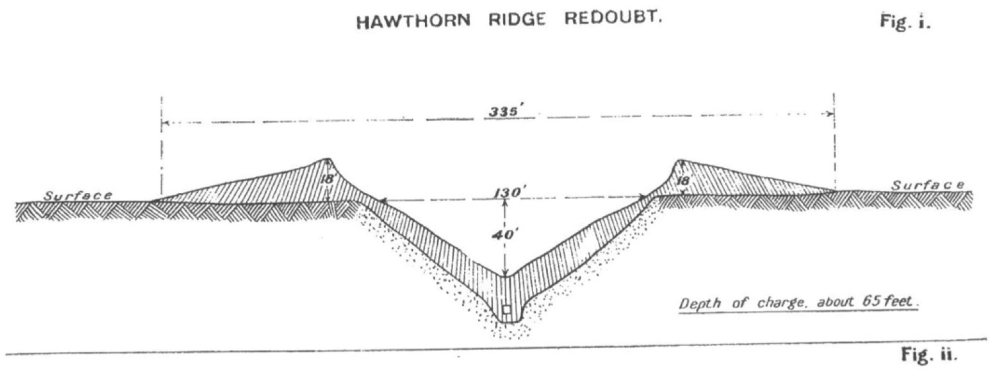

Figure 6. Contemporary sketch labelled as the Hawthorn Ridge mine crater as exploded on 1st July 1916, showing the build-up of debris to form the crater lips (From Institute of Royal Engineers 1922, pl XV, Figure 1). In fact, according to Jones (2010, 124), this is the Y-Sap crater (with a gallery at 65 feet rather than 80 feet depth); but in general form, particularly with regard to the up-cast debris and crater lips, it is similar.

farther top of the crater and prevented farther advance' (Gillon 1925, 80; see also O'Neill 1922, 110). The War Diary of the 2nd Battalion Royal Fusiliers recorded this failure in stark terms: 'The big mine was exploded and "Z" Company rushed forward to occupy the crater, but were immediately met by heavy machine gun fire and artillery barrage. Five minutes after this (zero time) the general attack along the front was launched. Very few of our men reached as far as the enemy barbed wire'.

Though these men did reach the near lip of the mine, the Germans retained the far lip, preventing farther advance (Gillon 1925, 80). This was to have a terrible effect. Lieutenant V.F.S. Hawkins reported: 'Beaumont Hamel opposite the 29th Division was a veritable fortress. The 29th Division never got near the Hun Line' (Mace and Grehan 2013, 129). By noon of the first day of the Somme battle, the crater had been relinquished by the British, the plans to consolidate it abandoned (Jones 2010, 118). Following the failure of the British attack, the Germans proceeded to incorporate the crater into their lines, 'fortifying it with dug-outs' and making 'considerable use of it both as an observation post and as a position for snipers' (Bewsher 1921, 113).

As noted above, the Hawthorn Ridge Crater actually comprises two large intercutting mine craters, with a deformed south-eastern edge, consistent with the explosion of two mines from the same gallery; a larger crater associated with the controversial main blast carried out at 7.20 am on 1 July 1916; and a smaller crater associated with a much more successful explosion at 5.45 am on 13 November 1916. This second crater was formed by a 30,000 lb charge of ammonal set in place in the original tunnel gallery on 30 October 1916.

To create the second explosion, the mine gallery was reopened by the British 252 Tunnelling Company just 4 days after the explosion of the first mine (Jones 2010, 131). A 30,000 lb charge of ammonal was set in place in the original tunnel gallery on 30 October 1916 resulting in a smaller, overlapping, crater formed by its detonation at 5.45 am on 13 November 1916 , at the last stage of the Battle of the Somme – usually known as the Battle of Ancre. This explosion, and its associated artillery bombardment, was entirely successful in that it allowed the attacking 5th and 6th Seaforth Highlanders (51st Highland Division) to

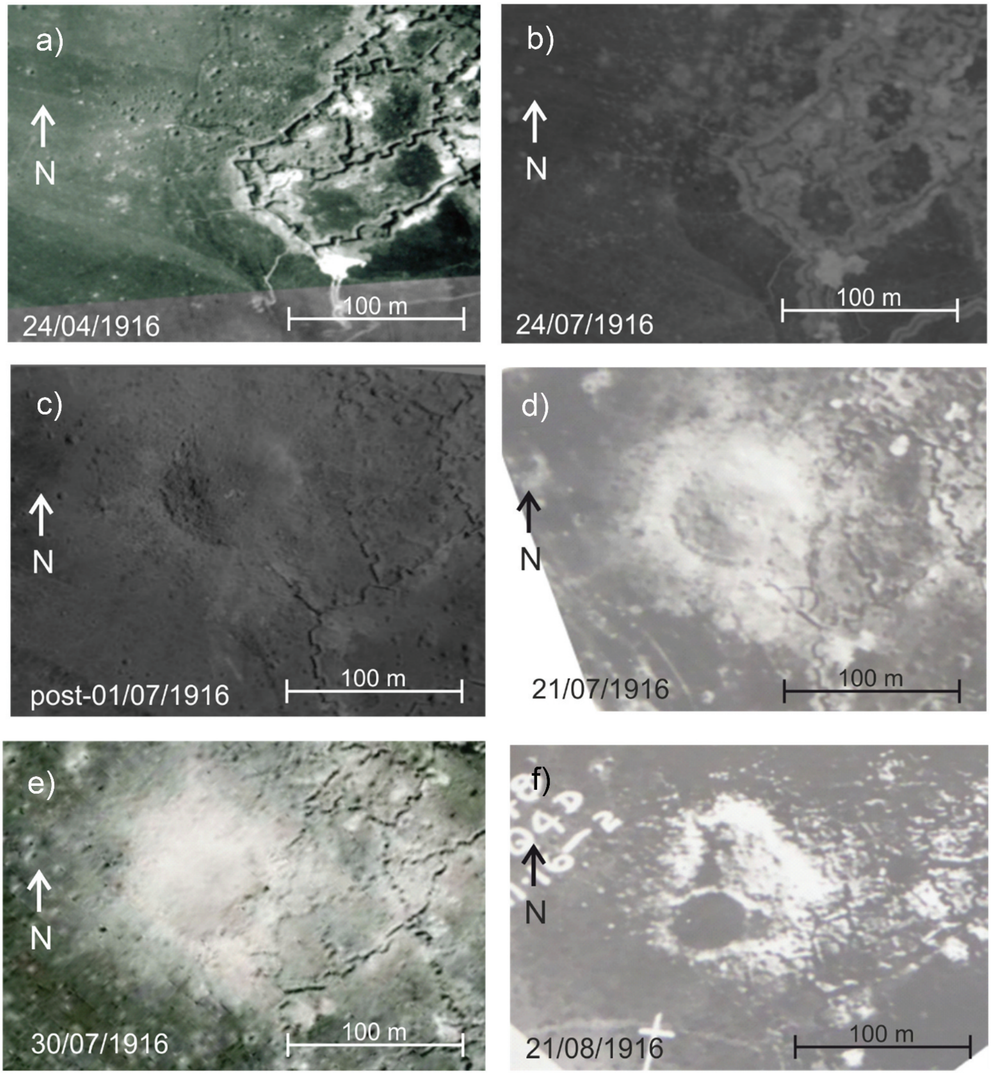

Figure 7. Contemporary aerial photographs of the Hawthorn Ridge Redoubt, taken before (A-B) and after (C-F) the first mine was blown on 1st July 1916. The German trench system comprising the Redoubt can also be clearly seen on the right [east] side of the photographs. From IWM digital archives.

carry the frontline trenches, assisted by thick fog, and to finally capture the village of Beaumont Hamel, which had been such a prominent feature of the German frontline position (War Diaries, 5th and 6th Seaforth Highlanders 1916; Bewsher 1921; Jones 2010).

Initial reconnaissance of the craters

Today, the two sub-craters at Hawthorn Ridge survive in the landscape as a testimony to these two actions in 1916 and are situated 200 m west of the village of

Beaumont Hamel, north of the Ancre River, and to the east of Auchonvillers, at the head of a dry valley (Figure 5). Here, the Somme comprises a Cretaceous chalk plateau covered by the *limons de plateaux* complex Figure 4), and the crater is developed in both chalk and *limon* soils.

In our survey, carried out in January 2018, a ~ 10-m-wide mound of upcast material was identified around the north and north-western edge of the northern crater, consistent with the explosion of the mine, and a slight slump of material and a sub-circular mound surrounded the south-western edge of the southern crater. Smaller craters/depressions were also observed that are consistent with artillery shell holes (Figure 16).

The Hawthorn Crater Association was formed in 2018 to preserve and protect the iconic site, to research and share knowledge and that of other historians (WRCA 2023). The Association began groundworks to improve site access, which involved stripping vegetation from around the lip and slopes of the northern crater (Figure 8). This exposed regular rectangular features, varying in width between 2.5 m and 3.5 m wide. Between these, placed on the internal edge of the northern crater were mounds of earth, regular in size approximately 1 m to 1.5 m wide, the earthworks resemble a typical trench system of firebays and traverses, consistent with crater 'consolidation' by the Germans following the failure of the initial assault by the British. The features did not extend to the south-west and into the southern crater lip; the southern crater sides were sharp and steeper than the gradual concave sides of the northern side.

Tourist activity and damage by burrowing animals have contributed to erosion to the two intersecting craters. However, the archaeological features identified during initial reconnaissance were most at risk. Animals had created extensive burrows and warrens that were rapidly undermining the potential defensive earthworks. This was most obvious at the southernmost firebay, which was exposed to the elements, and showed signs of deterioration due to erosion.

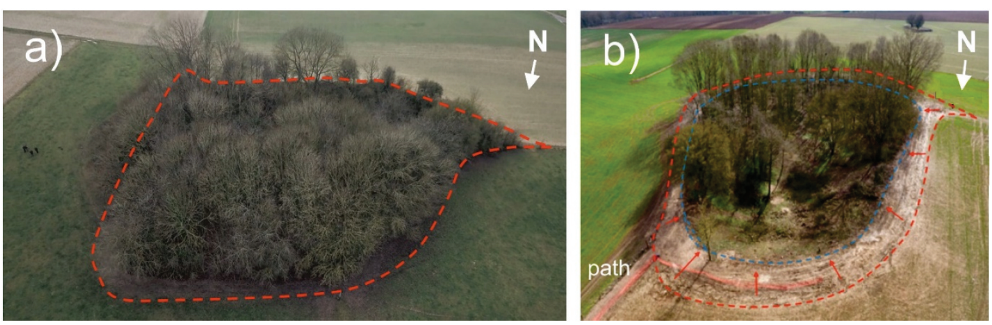

Figure 8. Modern photographs showing: a) Hawthorn Crater on 6th January 2018, during an initial reconnaissance of the site (red dashed line shows extent of tree line) and b) 2019 image which shows trees and vegetation site clearance by the Hawthorn Crater Association, and path with surrounding metal fence (red dashed line shows new tree line).

Methods and data acquisition

Remote digital data acquisition

Remote sensing methods gather information about a physical object, the ground surface, or beneath the ground without the need for direct contact (Ruffell and McKinley 2008), good practice in aerial archaeology using LiDAR would be to create a digital surface model of the ground survey site (see Entwistle, McCaffrey, and Abrahams 2009; Johnson and Ouimet 2014) but was not undertaken in this study. Typically, such techniques allow researchers to then identify features or potential areas of interest that may not be seen at ground level, which can then be looked at in further detail using a variety of other techniques (Ruffell and Wach 2019).

Ground surveys can then accurately map remaining features that can still be observed. Geophysical surveys are commonly used as they can penetrate up to 10 m below ground level (bgl) as well as to detect relict features and characterise them; this is especially true if a combination of techniques is used (for example, see Ainsworth et al. 2018; Rees-Hughes et al. 2016; Reynolds 2011).

Remote drone surveys

Drones equipped with multispectral cameras/sensors/filters can detect wavelengths of lights not visible to the human eye. Image interpretation can then be used to locate buried archaeological features. These archaeological remains often retain different percentages of soil moisture compared to surrounding areas, thus indirectly leading to enhanced (positive) or diminished (negative) crop/vegetation growth – these differences are reflected by the different colours presented within the image(s) (see Sarris et al. 2013; Agapiou et al. 2013; Hill, Laugier, and Casana 2020). A DJI Mavric ProFlight drone, equipped with FC220_4.7_4000×3000 (RGB) camera, with an average sampling distance of 1.58 cm, was deployed over the 10 Acre survey area and collecting 470 individual images. Data was processed inhouse using Pix4D (mapper) and Pix4D (fields) software.

Ground-based surface surveys – total station

Total stations are optical distance-measuring instruments capable accurately recording the position of topographic features and artefacts that can map conflict archaeology sites (e.g. Doyle and Bennett 1997). A total station survey was used to accurately measure the extent of the crater margin(s), marker points and precise parameters of the geophysical survey grids within the crater, using a Leica TCRP1205 Pinpoint R100 total station in conjunction with a 360° GRZ4 theodolite prism reflector (Figure 9). It was also used to position subsequent geophysical survey lines due to the trees preventing accurate dGPS readings to be recorded. Total station surveys were then used to map recovered contemporary artefacts and obstacles.

Ground-based surface surveys – LiDAR

Ground-based Light Detection and Ranging (LiDAR) surveys rapidly generate data point clouds that can be RGB coloured to produce almost photo-realistic but mappable

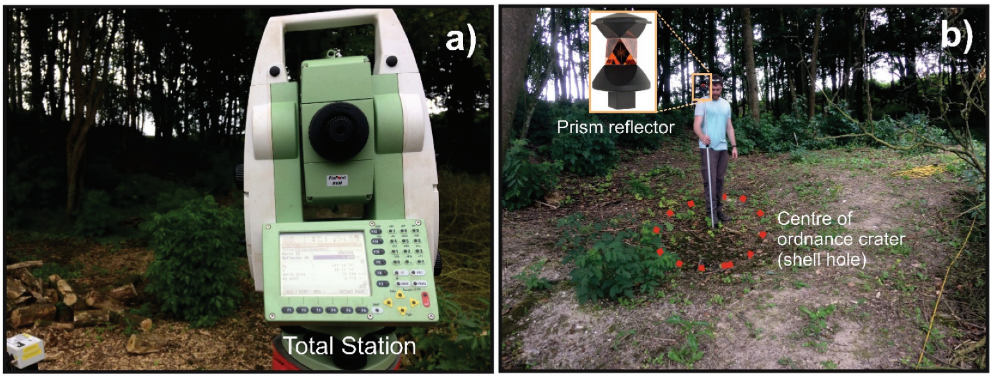

Figure 9. Hawthorn Crater site photographs of a) the Leica TCRP1205 pinpoint R100 total station onsite; b) total station 360° (GRZ4) theodolite prism, taken at central point of one of the numerous ordnance craters on the eastern side of hawthorn crater.

accurate datasets that can be later viewed from any direction and interrogated (see Rees-Hughes et al. 2016).

A tripod-based FARO Focus 150 terrestrial laser scanner was used onsite to collect 10 separate surface laser scans within the crater, with positions deliberately overlapping fields of view for later data merging. Data point accuracy was <5 mm up to range of 150 m from the scanning hardware. Note the extensive tree cover within the crater at the time survey (Figure 9) necessitated 10 scans to reduce data shadows being potentially produced from the above-ground vegetation. Individual scans were subsequently integrated into a single dataset before Farozone Scene11 software processed the dataset, to produce a DEM point cloud of the survey site and some above-ground vegetation being removed.

Near-surface geophysical surveys

Non-invasive surface geophysical techniques have previously been successful in First World War conflict archaeology sites (e.g. see Francese et al. 2019; Gheyle et al. 2022; Masters and Stichelbaut 2009). Specific geophysical techniques utilised for archaeology vary depending on the target, local environment and equipment availability (see Gaffney 2008). EMI is used for large-scale surveys to detect areas for follow-up investigations (e.g. De Smedt et al. 2014), which was not the focus of this study. GPR is a commonly-used higher-resolution technique for detecting isolated near-surface objects, particularly in conflict archaeology sites (e.g. Francese et al. 2019), but due to the major site topographic changes and deciduous trees and associated onsite, it was decided not to use this method for this study.

Due to restricted site access in the surrounding fields away from the crater, data collection was only possible within the perimeter of the crater. Although some of the site was cleared before the geophysical survey began (Figure 8(b)), the steep sides and uneven ground, in combination with established vegetation, meant that it was difficult to collect data in some areas of the crater. The fields surrounding the site were agricultural and their boundaries marked with metallic wire fencing (see Figure 9(a,b)), which particularly affects electromagnetic and magnetic gradiometry geophysical surveys, could not be removed prior to fieldwork.

Magnetic gradiometry survey

Magnetic surveys are the most common in archaeological site investigations (see Fassbinder 2015; Lowe 2012; Masters and Stichelbaut 2009) and applications in the detection of unexploded ordnance (UXO) and other metallic artefacts, as well as to detect more subtle buried items of interest, for example, foundations, ditches, roads etc (Masters and Stichelbaut 2009).

Following calibration in a magnetically quiet area of the site, a Bartington™ Grad601 Single Axis fluxgate gradiometer was used to acquire magnetic gradient data at ~0.1 m sample intervals along 1 m spaced survey lines. This was challenging due to the steep topography, above-ground vegetation and relatively poor GPS positioning obtained due to overhead vegetation. A relatively high 1000 nT collection range was used due to the many metallic objects onsite. A standard processing sequence was applied using Microsoft Excel software (following the Ainsworth et al. 2018 methodology). Anomalous data points due to acquisition issues were firstly removed, termed 'despiking', and non-target long wavelength trends in the data removed, 'detrending' (see Milsom and Eriksen 2011 for background) before the data was gridded.

Electrical resistivity survey

Electrical resistivity methods have also been a regular approach in archaeological investigations (see Dick et al. 2017; Terron et al. 2015; Thacker, Ellwood, and Pereira 2002). Generally, the method is cheap, easily manoeuvrable, and data are rapidly collected. The investigation depth is dependent on the electrode probe spacing (see Milsom and Eriksen 2011 for details).

After testing with different probe spacings and sample intervals, a Geoscan™ RM15-D Resistivity Meter, using a parallel Constant Separation Traverse (CST) twin-probe array setting, was used with a probe separation of 1.5 m, to acquire resistivity readings at 0.25 m sample intervals over each survey line within the central crater region. The data were then downloaded, despiked and detrended using Microsoft Excel software using standard processing (following methodology in Ainsworth et al. 2018).

Ground-based archaeological survey

Careful invasive archaeological investigations were conducted at positions of interest in 2018, based on features observed on the surface of the crater, and any areas of interest identified by the geophysical surveys. The objectives were to: 1, assess and record the current state of preservation and identify any archaeological features that may be at risk; and, 2, identify the sub-craters and the extent of the upcast material associated with the detonations of 1 July 1916 and 13 November 1916. To complete this, archaeological features were carefully excavated using hand tools and recorded using sketches, measurements, and photographs throughout.

Members of the academic team obtained ethical approval to conduct this project. This primarily addressed ethical issues regarding the discovery of human remains and how they would be recovered, identified, and repatriated. This adhered to current procedures and legislation outlined by the Commonwealth War Graves Commission (UK casualties), Volksbund Deutsche Kriegsgräberfürsorge e.V (German casualties), and Souvenir Francais (French casualties). Similarly, if human remains were found on site, and according with protocol, the local Police would have been notified immediately. No human remains were encountered.

Results

Remote drone survey

A combined georeferenced image and a digital surface model was generated (Figure 10). The dense tree canopy within the crater meant that it was not possible to record any ground topographic features using multispectral imaging. However, both the orthomosaic and near-infrared images (Figure 10(a,b) respectively) showed a subsurface feature at the North-West of the crater, running parallel to the direction of plough markings, which

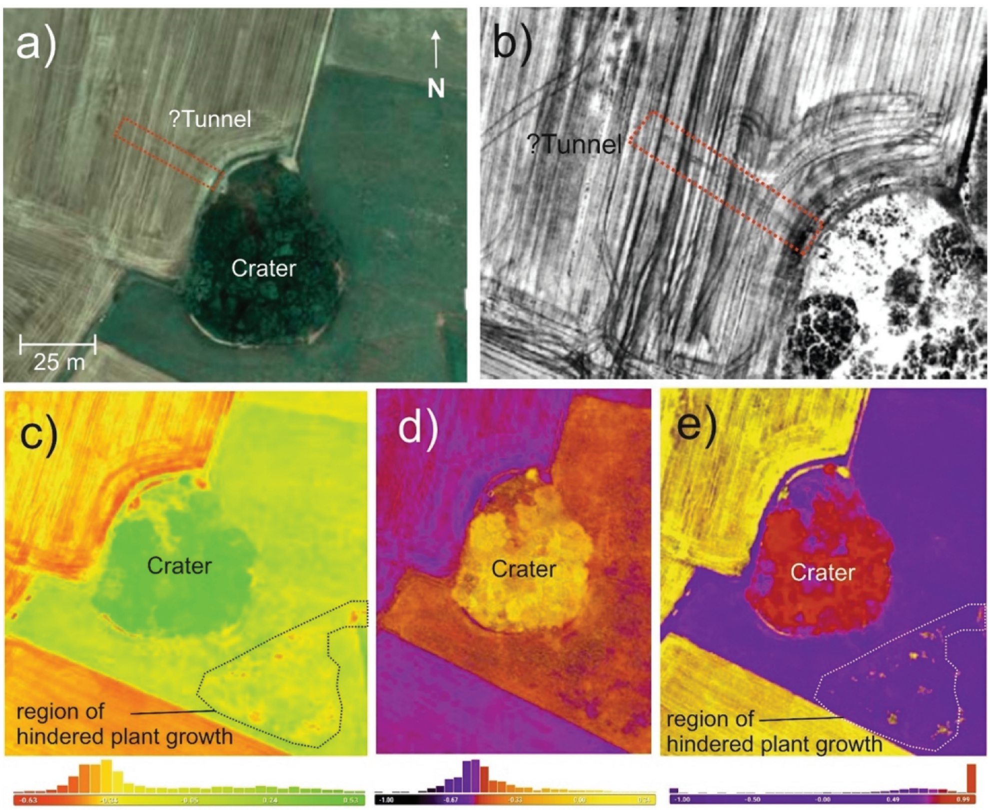

Figure 10. Multispectral interpreted images of Hawthorn Crater showing: a) orthomosaic image with potential sap location highlighted (red dashed box); b) near infrared image with tunnel location highlighted (red dashed box); c) 'green normalised difference vegetation index' [GNDVI] image showing main crater and area of poor plant growth; d) 'leaf chlorophyll index' [LCI] image showing main crater area; e) 'structure intensive pigment Index2' [SIPI2] image showing main crater and area of poor plant growth.

we interpret as a shallow tunnel or sap, typical of such defensive works. Unfortunately, this could not be intrusively investigated, as this is private land.

Areas of relatively poor plant growth were also observed (Figure 10(c–e)), the cause of this is unknown and required further investigation to determine whether this relates to effects associated with the crater and its battlefield context. Soil samples collected and analysed did not show high levels of heavy metal contamination (see Pringle et al. 2022). Sections of the path around the outside crater, not covered by the tree canopy (north and southeast of the crater), were also observed as a region of bare land using GNDVI, LCI and SIPI2 imaging.

Ground-based LiDAR survey

The combined LiDAR 10 scans dataset allowed overhead and panoramic digital views of the crater to be generated (Figure 11 and Appendices digital fly-through) that could be interrogated, site measurements and plans made, as well as to determine the extent and position of vegetation/other obstacles. Ideally, overlying vegetation would also have been removed to show just the crater itself (e.g. see Ainsworth et al. 2018 for example) but was not done in this case due to the operators restricted time on the project.

The LiDAR dataset also allowed both an aerial and cross-sectional view of the modern-day site, which pinpointed the epicentres of the two separate mine detonation locations

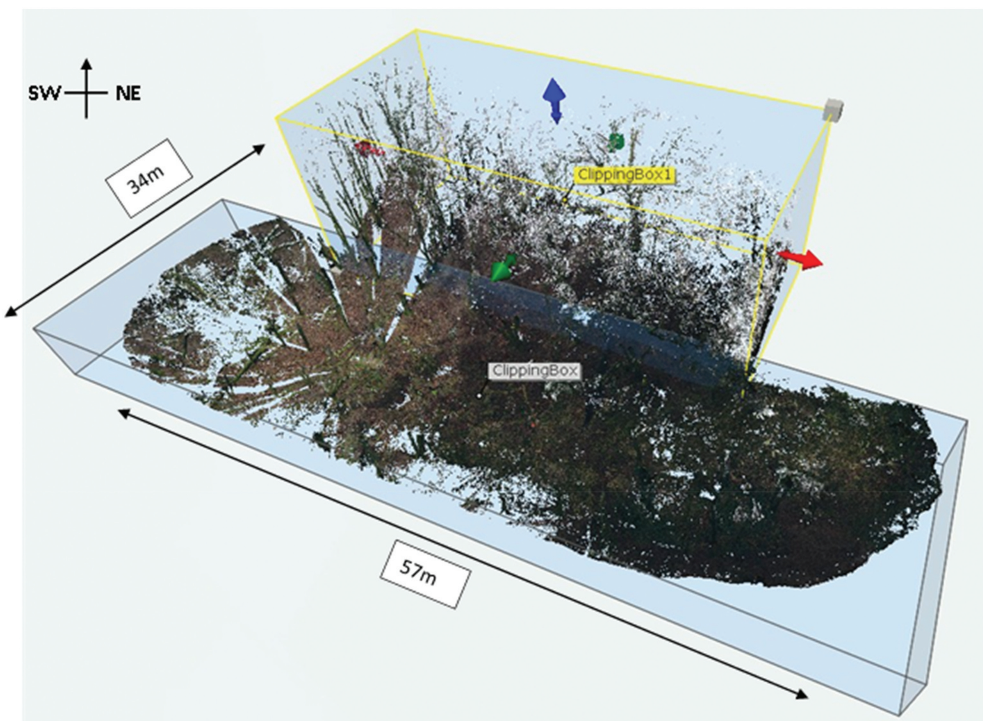

Figure 11. Terrestrial LiDAR RGB-coloured data point-cloud annotated section of Hawthorn Crater. See supplementary data for digital fly-through of the crater dataset.

in July and November 1916 respectively. The noticeably larger northern crater, which was detonated on 1 July 1916, a greater amount of explosive, was 54.1 m diameter and now has a maximum surface depression depth of 10.8 m, compared to the 34.3 m diameter and 12.6 m surface depression depth of the southern crater, detonated on 13 November 1916.

Ground-based surface survey

A total station topographic survey of Hawthorn Crater, positions of trees that may influence resistivity results, the two sub-crater epicentres and 27 identified post-explosion ordnance impact shell holes, which were observed to be distributed at an increasing frequency towards the east of the Hawthorn Crater epicentre (Figure 12). This, in addition to the elliptical geometry of the ordnance shell craters, with the backwall assigned at an eastern direction, suggests the trajectory of incoming artillery shells post-explosion to have originated from the British lines; entirely consistent with British and German front-line positions in 1916 (Figure 5).

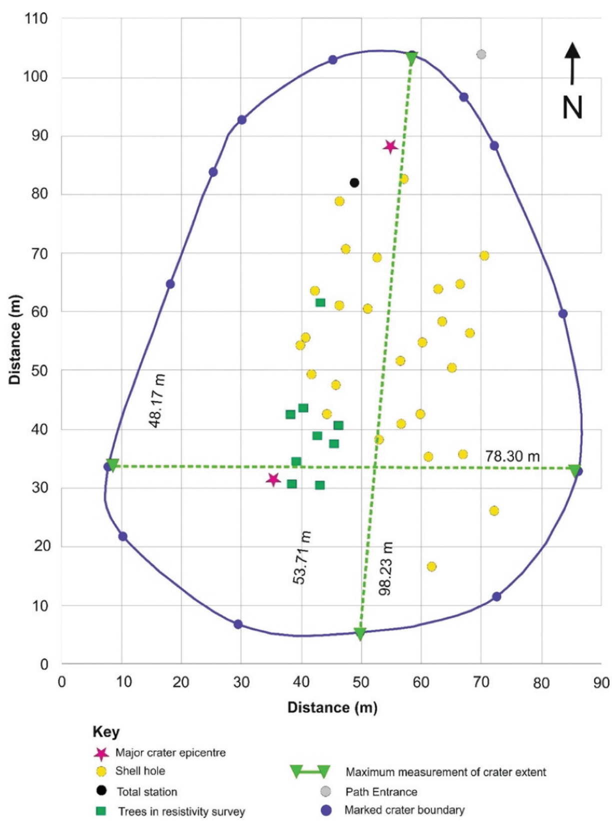

Figure 12. Ground-based total station surface survey, showing Hawthorn Crater boundary, two sub-crater epicentres, trees and post-crater formation shell impact holes.

Near-surface geophysical results

Magnetic gradiometry survey

Magnetic gradiometry data results were highly variable, with regions of relatively high magnetic values particularly observed in the northwest and south-west of the crater that may indicate relatively high concentrations of near-surface ferrous buried objects (Figure 13). Interestingly, some discrete magnetic anomalies were observed over the surveyed shell impact shell holes, suggesting some UXO metallic debris may still be in place near the surface. Other metallic anomalies could not be interpreted as due to either trench systems, cut-and-cover dugouts or wire which are commonly found in other magnetic surveys on this conflict area (See Masters and Stichelbaut 2009).

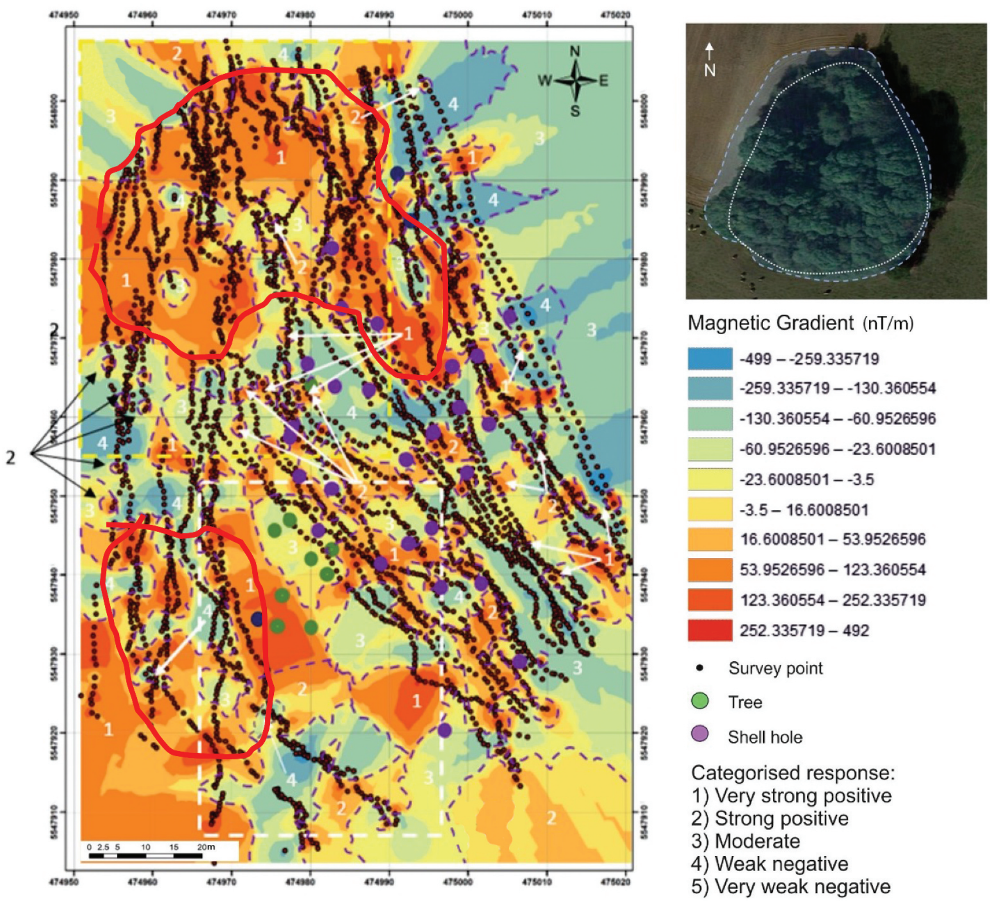

Figure 13. Magnetic gradient-processed results and relative survey location (inset) of Hawthorn Crater with black dots indicating measurement positions. Magnetic gradient anomalies have been categorised from 1 (very strong) to 5 (very weak) responses (see key), with red rings showing regions of high magnetic response. Green dots indicate tree positions and purple dots are surveyed ordnance shell holes (see key).

Bulk-ground electrical resistivity survey

Electrical resistivity data results were less useful, showing areas of relatively high resistance values in the centre and north of the survey area but these were very large features that were thought not be directly related to conflict archaeology (Figure 14). The central area is relatively wooded, with tree roots reducing soil moisture content and hence, mostly likely, increasing the observed surface resistivity values and being the cause of the large central anomaly. Nevertheless, the areas of high resistance are significantly larger than the tree positions so may be due to other causes, containing more resistant material.

Archaeological investigations

Surface finds

Metallic artefacts consistent with battlefield debris were found around and within the interior of the crater surface. These finddings mainly included shell case fragments, shrapnel balls and 'push plates' consistent with shrapnel shells fired, typically from the 18-pdr Field Gun that made up much of the British ordnance then deployed (Sheffield 2003, 36; War Office 1915, 170–191) (Figure 15). A fired but unexploded shell (a 'dud') was also found, representative of the large number that failed to explode on the Somme. Such a concentration of metallic items will naturally result in geophysical anomalies (e.g. Saey et al. 2016) and directly influence metal concentrations in the soil (e.g. Note et al. 2018).

Intrusive investigations

Careful intrusive investigations were then carried out, the data collected suggesting the northern edge of the main crater would bear further examination, particularly as this is where the suspected tunnel sap joined the crater rim as identified on the remote sensing data. On the northwestern rim of Crater 1, a rectangular firebay feature was excavated, and cleaned using hand tools, in order to expose the extent of the bay, henceforth referred to a firebay 1 (Figure 16). The decision was taken onsite to only excavate half of the bay, thereby creating a section to understand how it was created, its use and possible maintenance. While the firebay was visible as a cut feature within the upcast material from the mine, the base of the bay was exceptionally difficult to identify, as the true extent of the damage by burrowing animals was greater than initially expected.

The base of the upcast material which sealed the *limons de plateaux* (Doyle 2017a) was encountered, containing large quantities of tangled German barbed wire (Figure 17(a)) possibly from the original defensive wire belt typical of consolidated craters, which had compacted the surrounding geology. A possible north-south orientated trench base was also identified, cut into the *limon de plateaux*, in which probable communication wire and distinctive German barbed wire (identified by its square cross section) was recovered. At the eastern edge of this trench base was a mound of upcast material from the establishment of the defensive works. Thin laminated layers of chalk and *limon* had been placed to create a small parados, within which a British Vickers Machine gun ammunition box was recovered.

A second area was investigated where the linear feature, identified from the remote sensing data joined the crater position. This was further to the north of the first excavated firebay location. This was investigated due to the potential of identifying the shallow

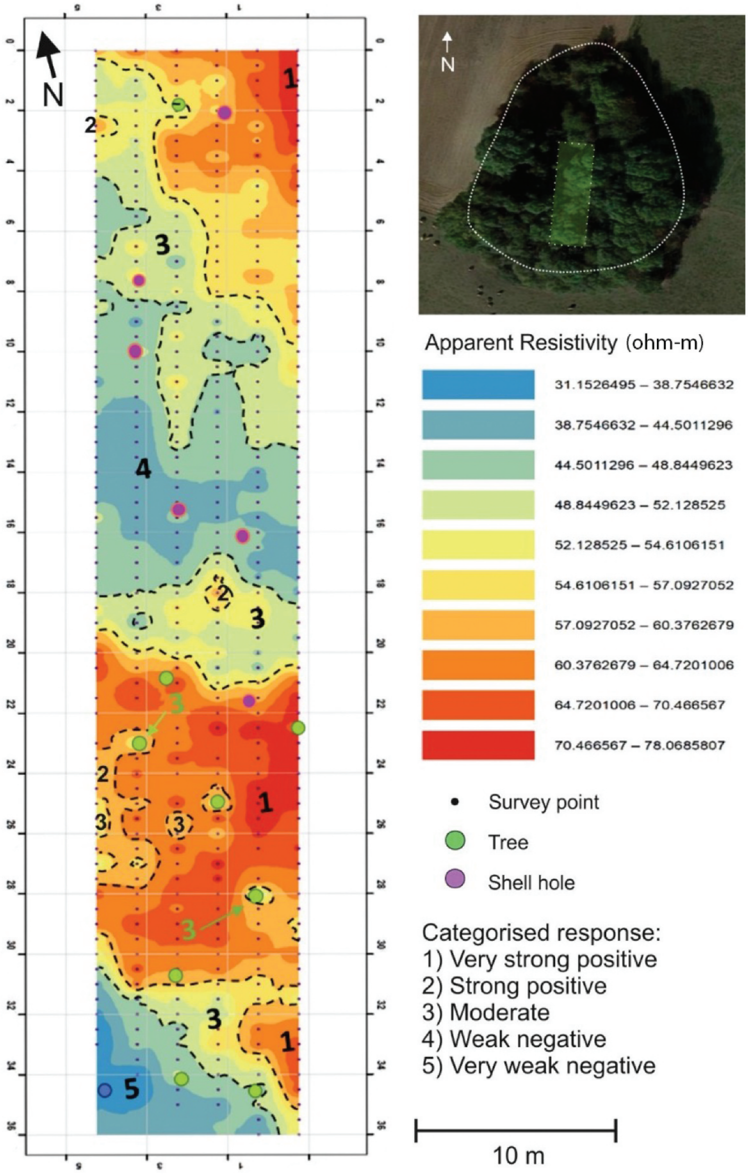

Figure 14. Electrical resistivity processed results and relative survey location (inset) of Hawthorn Crater with black dots indicating measurement positions. Electrical resistivity anomalies have been categorised from 1 (very strong) to 5 (very weak) responses (see key). Green dots indicate tree positions and purple dots are shell impact holes (see key).

tunnel or sap typical of trench warfare (Figures 10(a,b), 16). When excavated, although heavily damaged by large tree roots, it was found that there was an additional firebay similar to that identified farther south.

Both firebays are consistent with the type of short stretches of trenches used to consolidate newly-formed craters (Figure 17). As one of the purposes of

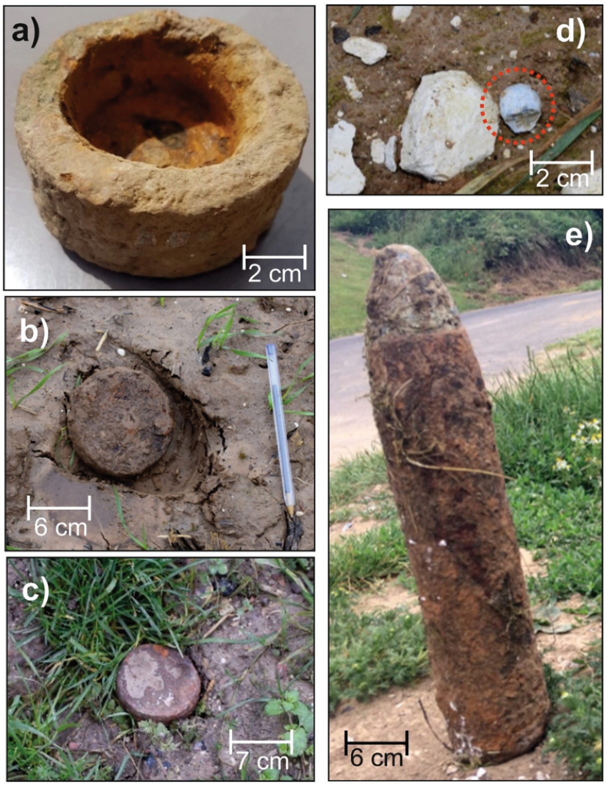

Figure 15. Photographs showing examples of surface finds within and near to Hawthorn Crater: a) British 18-pounder shell base with copper driving band; b) shrapnel push plate believed to be from a British 18-pounder shell; c) a 'modified' push plate from an unidentified shell; d) 11g lead shrapnel ball, thought to have originated from a British shell (e.g. see image a and; e) unexploded British 18-pdr shrapnel shell with time-fuse intact.

overcharging a mine was to create an obstacle within No Man's Land it was essential to capture the crater in the assault (see General Staff, War Office 1916). Given that this feature was situated on the north-western rim of Crater 1, created by the explosion of the original mine on 1 July 1916, these defensive works were German in origin, as the crater was not captured until the last phase of the Somme battle. This was supported by the evidence of the German barbed wire found *in situ*. The presence of a presumed sap is also consistent with these defensive works, as saps were routinely constructed by defenders to provide an advanced position in No Man's Land.

Very few artefacts were recovered relating to the true function of this bay, although a single spent German 7.92 × 52 mm Mauser cartridge case was recovered with a 1918 date stamp, therefore post-dating the Battle of the Somme 1916, but potentially from the actions of 1918, either when German forces recaptured this ground in the *Kaiserschlacht* Offensive in March, or the subsequent retaking by the Allies in the August Hundred Days Offensive. It is suggested that this part of the crater should be subject to future investigative work in order fully understand it.

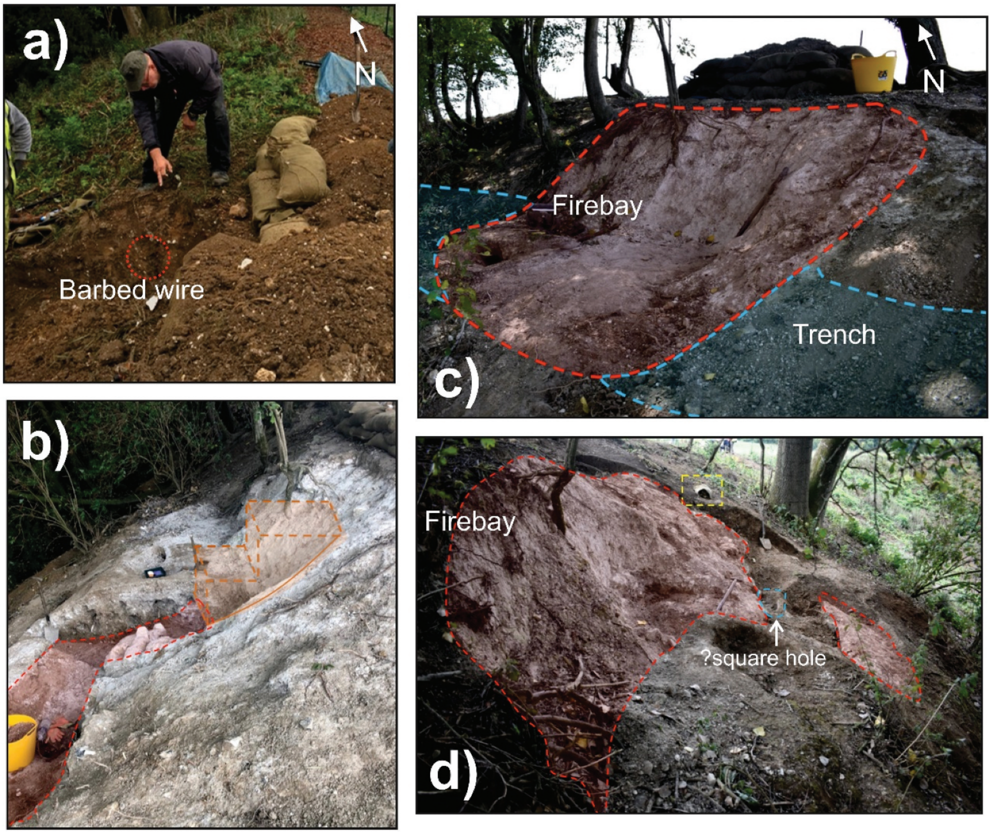

Figure 16. Excavations of firebay 1 in the northwestern rim of Crater 1 (see Figure 17 for location). a) excavations in progress exposing German pattern barbed wire. Note the sandbags are modern; b, section through the firebay, showing it is grounded in chalk debris; c), d), alternate views of firebay I, to the southwest (c), and northeast (d).

Discussion

The first aim of the project was '*to provide background and existing information of the Hawthorn Redoubt Crater*'.

This has been detailed in this paper, providing crucial information for the later multi-disciplinary investigations.

The second aim of the project was '*to conduct careful non-intrusive modern site investigations*'.

Remote sensing UAV multispectral imaging did not penetrate through the crater tree canopy which was expected, but near-infrared UAV imaging revealed a probable sap or shallow tunnel to the northwest of the crater, with the orientated NW-SE and potentially coming across the crater rim (Figure 10). Ground-based LiDAR surveys produced a detailed scan of the crater, allowing top- and side-views of the crater to be generated that permits a fuller examination of its formation (Figure 11). The initial detonation of 40,000 lbs ammonal on 1 July 1916 produced a crater that was 130 feet (39.62 m) in diameter and 58 feet (17.67 m) (Edmonds 1932, 432, footnote 2). Months of progressive

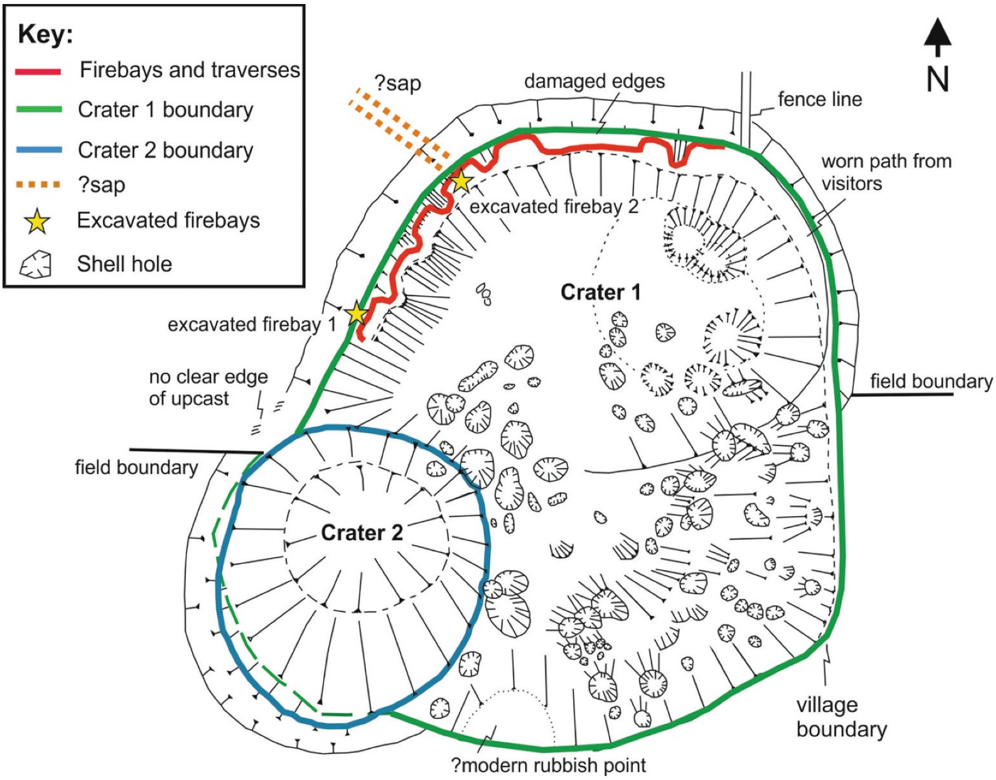

Figure 17. Hawthorn Crater sketch map showing a summary of research findings. As well as the two craters identified, German-constructed firebays and traverses suggested locations are shown, together with the post-crater formation, probably allied shell ordnance craters.

shelling and aerial erosion until the detonation of the secondary smaller charge, 13th November, which obliterated and subsequently superimposed itself onto the Southern margin of the first crater. The second blast produced a crater of 34.3 m diameter and depth of 12.6 m. Exposure to further military action, weathering, and tourist activities etc, resulted in deterioration of the crater lips and the central intersection between the two crater margins. Total station surveying was found to be effective to accurately map relict features as other WW1 researchers have evidenced (see Pollard 2014), also interestingly finding post-crater formation ordnance shell holes were mostly in the east, thus suggesting they were due to the British artillery lying to the west at this time (Figure 12).

The geophysical surveys were geophysically noisy although the magnetic gradiometry surveys showed relatively high magnetic responses to the north-west of the site (Figure 13). Better results have been shown using these techniques at other conflict archaeology sites (see, for example, see Ainsworth et al. 2018; Carr et al. 2020; Rees-Hughes et al. 2016; Reynolds 2011), this was most probable due to the difficult nature of the site, with surrounding metal fence, steep topography, dense and overlying vegetation causing issues with instrument height, GPS positioning and equipment calibration.

The third aim of the project was '*to conduct careful intrusive investigations to ground-truth results*'.

This is commonly undertaken in First World War conflict archaeological sites on the former Western Front (see Banks 2014; Masters and Stichelbaut 2009). The careful excavations carried out on site have concentrated upon the northwestern crater rim, and all evidence from this shows a small section of trench works and firebays that are evidence of crater rim consolidation. Though this would have been the aim of the attacking British forces in July 1916, as the crater was not captured by them – due to the ill-advised early explosion of the mine – these works, including the sap identified here, clearly post-date the initial assault. They are therefore likely to be German in origin, created to consolidate the crater into the German line following the assault on 1 July 191 6. This act created a significant obstacle in No Man's Land, further hampering British attempts to capture the frontline in 1916, only overcome by the successful assault four months later. Artefacts recovered during the archaeological works suggest that these positions were reused during the German Spring Offensive of March 1918 and/or the Allied Hundred Days Offensive of August that year. Much more work remains to be done in this sphere. It was not possible to undertake deeper site investigations such as documented by Banks (2019).

The fourth and final aim was '*to determine the optimal site investigation techniques for others to utilise on similar conflict archaeology sites*'.

The use of historical aerial photographs, maps, and other literature can aid in identifying geophysical anomalies as other modern investigations of historical sites have shown (see, for example, Pringle et al. 2007; Doyle, Barton, and Vandewalle 2005; Stichelbaut et al. 2017; Ainsworth et al. 2018). British trench maps are available for this site, and showed the distribution of German frontline trenches in the Hawthorn Ridge area before and after the explosion of the mine (Geographical Section, General Staff 1916a, b). These maps were at the scale of 1:10,000, but add little detail to the interpretation of the ground conditions. A detailed analysis of the aerial photography of the site would be beneficial, and though this was outside the scope of the present study, it is the next obvious step to take in further investigations. Remote sensing UAV drone NIR data did highlight a linear feature that may have been the potential sap, but it was not able to be investigated here. Non-invasive geophysical investigations were geophysically noisy due to the high deposition of metal contaminants typical of a battlefield that has been documented by others (Stichelbaut et al. 2017), but the north-west section was able to be highlighted to be intrusively investigated (Figure 13), which found German trench (firebay) systems (Figure 16). As acknowledged by Stichelbaut et al. (2017), the various terrains, soils, post-depositional processes, and varying availability of historical sources means that there is no 'one fits all' approach to this type of war heritage and so all available datasets should be implemented, where possible. Other authors investigating such conflict archaeology sites have also shown phased site investigations can be effective (see Gheyle et al. 2022; Ruffell and Wach 2019). To aid geophysical data collection we recommend that non-conductive (i.e. wooden) fences are used to cordon off the boundaries of similar/other sites, as the presence of the above-ground metallic fence on the perimeter of the crater may have been responsible for the high conductive/magnetic regions. Similar issues have also been reported elsewhere (Dick et al. 2015), with advanced processing needed to remove the effect of near-surface metallic clutter from the data. A suggested conflict archaeology multi-disciplinary workflow is provided in Figure 18, although note it is unlikely that all the available datasets, investigatory equipment and expertise is available for all site studies.

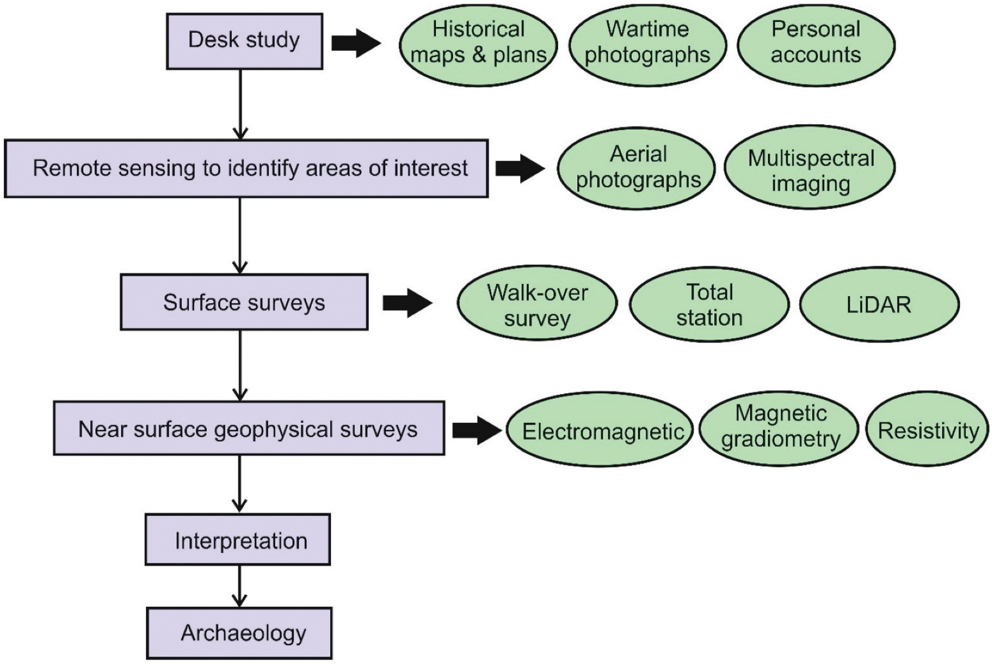

Figure 18. Suggested workflow for a multi-disciplinary scientific investigation approach to analyse conflict archaeology sites as employed in this case study.

Conclusions

The Hawthorn Ridge Crater in Beaumont Hamel, Northern France, is of great historical and cultural significance; detonated ten minutes before Zero Hour on 1 July 1916, it would become associated with the British Army's failures to capture the broad front of the German trenches as part of the Somme Offensive. It was captured on film by cinematographer Geoffrey Malins, and for this reason remains an icon of trench warfare. Our study was the first multi-disciplinary scientific investigation to be undertaken at the Hawthorn Crater once the Hawthorn Ridge Crater Association took physical possession of the land in 2018. Remote sensing, ground and near-surface geophysical surveys have quantified the crater, and in fact two sub-craters, that were produced by the two separate mine explosions using the same mine gallery, on 1 July 1916 and 13 November 1916, which effectively 'bookended' the Battle of the Somme. Surface surveying mapping has also shown that the post-explosion ordnance shell holes, from their position and angle, would have been fired by British troops who had failed to take the first crater on 1st July, and who would only capture it on 13th November with the explosion of the second mine. Geophysical data results were mixed, although the magnetic gradiometry data showed anomalies on the western lip that subsequent invasive archaeological investigations have shown were due to multiple fire pits, barbed wire, communication equipment and steel trench reinforcement that were German in origin, an attempt to consolidate the mine crater as a significant set defensive works in the aftermath of the first explosion in July 1916, and which would be used in combat up to and including the offensives and counter-offensives of 1918. Our work has shown that part of these German measures include a shallow tunnel or sap, showing the thoroughness of their defences.

The geophysical element of this study was limited by the steep terrain, overlying vegetation and surrounding metal fences, as well as a lack of access on surrounding fields. Further research at Hawthorn Crater is suggested, namely microgravity surveys to the northwest of the site to evidence if the 1916 mine tunnel gallery is indeed still present as indicated by the remote sensing data, and further targeted archaeological investigations, following geophysical interpretations/further data collection, to identify what further relict artefacts and structures may still remain in the very near-surface at this important cultural wartime heritage site.

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Geolocation information

The Hawthorn Crater Redoubt has the following geo-location co-ordinates: 50°04′59.9“N, 2° 39′01.1“E.

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