GeoScience Engineering

INTERPRETATION AND IDENTIFICATION OF UNEXPLODED AIRCRAFT AMMUNITION SITES FROM RECONNAISSANCE FLIGHT IMAGES

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ABSTRACT

This article describes the optimal work sequence for the interpretation and identification of unexploded aircraft ammunition sites from reconnaissance flight images of the area bombed during World War II. The described activities are based on a number of previous actions that were carried out within the framework of the MVČR security research project entitled "The search for unexploded aircraft ammunition from World War II". Two sites in the Czech Republic were selected for the project solution, which are among the most affected ones by the World War II bombing. With regard to the current knowledge and experience of the research team, a procedure of activities was suggested in order to secure the optimal quality of the results of interpretation and identification of the sites where unexploded aircraft ammunition can be found. The results may be affected by the frequency and quality of reconnaissance flight images and the information on the used aircraft ammunition. The quality of the results also depends on the quality of previous work in the creation of an orthophoto, personal experience and knowledge of the people working on the interpretation and identification of the images.

Keywords: Bombing; Interpretation and identification procedure; Orthophoto image; Stereoscopic evaluation; Unexploded aircraft ammunition.

1 INTERPRETATION AND IDENTIFICATION PROCEDURE

After the completion of work on all previous parts (site selection, acquisition of images from available databases, identification and control point fix, image transformation, creation of orthophotomosaics), which were finished by creating the orthophotos from several sets of images of the same area, the procedure of the identification and interpretation of unexploded aircraft ammunition sites in selected locations of the cities of Pilsen and Pardubice is further designed, tested and described.

Elementary activities necessary to complete the task:

- analysis of available text documents from Allied military archives and other resources in relation to the aerial bombing of the site in question;
- interpretation of historical images and identification of unexploded aircraft ammunition sites - includes the work with georeference images and orthophoto sets created using the procedures described in next section, stereoscopic evaluation of image pairs and mapping of identified unexploded ammunition sites;
- preparation of documents for field work – control excavations.

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pp. 1–15, ISSN 1802-5420
DOI 10.35180/gse-2022-0064

2 TEXT DOCUMENTS ANALYSIS

The analysis of the text documents is an integral part of the work necessary to correctly interpret historical images. The text documents related to the processed area supplement or confirm the timeline information of events interpreted by the analysis of historical images.

In addition to publicly available sources, declassified archive text documents obtained from the archives of the Air Force Historical Research Agency (USAAF documents) and The National Archives (RAF documents) were used in this section.

The main benefit was finding the necessary information directly from the Allied reports prepared during the planning and after the individual air raids. Among other things, it was possible to determine or specify the date, time, target and course of each air raid; the unit that carried out the air raid, including its composition; type and quantity (tonnage) of used aircraft ammunition and other facts.

The delivered documents were divided according to the date of the air raid and the unit that performed the air raid.

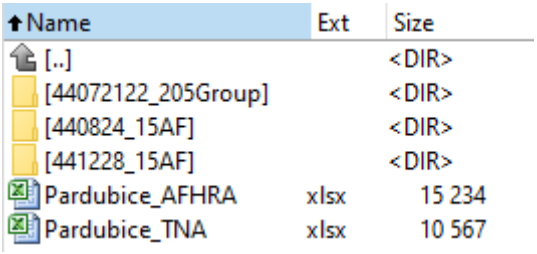

Figure 1. *Address structure of archive documents*

The structure of the archive documents varies depending on the air forces, but it always contains a general overview of the operations performed (e.g. Operations Record Book RAF) and the individual attachments - forms/reports, etc. (e.g. Attack Sheet, Briefing Sheet, Narrative Mission Report, etc.).

The USAAF summary table is coded (see Fig. 2), but using a key provides the necessary information, which is further elaborated in other documents of the air raid.

The sample contains the beginning of the record of the air raid against Pardubice on August 24, 1944, which was also carried out by the 2nd Bomber Group (in Table 2BG). According to the key, the letters "A A" found in the bomber group designation describe the type of mission ("A" means day bombing mission) and the type of target ("A" means airport). The following information includes the type of ammunition and fuse delay setting, where "KI" means 100lb GP Inst. (general purpose bomb). It is followed by an indication of the amount of dropped ammunition, i.e. 1026, tonnage, i.e. 5130 and the number of aircraft, i.e. 27. The data are confirmed by other documents which state, among other things, that each 2BG bomber carried 38 x 100lb GP bombs on board. The tonnage is listed here in the so-called American "short tons", where one ton is the equivalent to 2000lb. It is clear from the record that 27 2BG bombers dropped a total of 1026 x 100lb GP bombs, i.e. a total of 51.3 tons of ammunition.

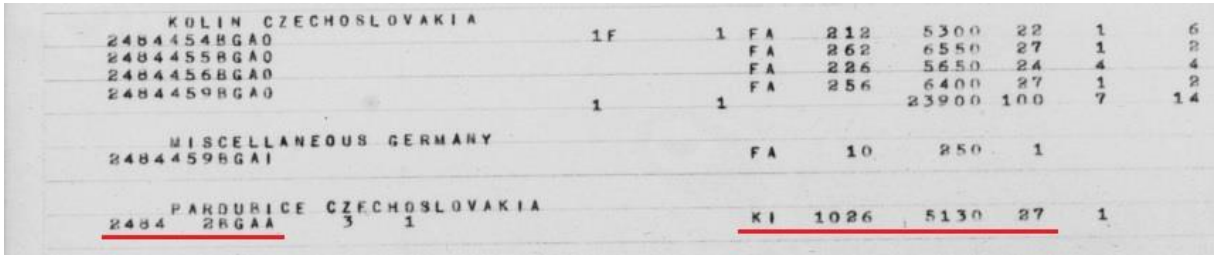

Figure 2. *Sample of summary table of USAAF operations*

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A total of 380 pages of declassified archive documents were analyzed in this section. The main result is the compilation of detailed overview tables containing information about each air raid.

Date	Unit	Number of Aircraft	Bomb Type	Target	Detail	Source
28.12.1944	US 15 AF	53	120 x 500 lb GP (1/10 x 1/100), 118 x 500 lb GP (1/10 x 1/40), 186 x 500 lb GP (1/10 x 1/100 or 1/10 x 1/40), 2 x 500 lb RDX (1/10 x 1/40), 62 x 500 lb RDX (1/10 x 1/100 or 1/10 x 1/40)	Pardubice Oil Refinery		AFHRA [1]

Figure 3. *Sample of summary table of Pardubice air raid from December 28, 1944*

2.1 Interpretation and identification of unexploded aircraft ammunition sites

The process of interpretation and identification of unexploded aircraft ammunition sites is based on the analysis of images from multiple time series. Chronologically arranged images from the period before the air raids over the site in question are gradually analysed and interpreted, up to the images taken after the last documented air raid.

The following parts summarize the prerequisites for identifying the unexploded aircraft ammunition sites that follow the successful solution of previous parts of the project:

2.2 Availability and quality of images

In ideal case, the images used for the interpretation were taken shortly before and after the air raid. This rule applies in particular to the identification of unexploded ammunition. The limiting factor is mainly the availability of archive images of the site, their quality and scale.

Fig. 4 shows the timeline of the air raids against Pardubice and their relationship to reconnaissance flight missions, during which the images for this project were taken. The average scale of the processed images in the evaluated locations is approx. 1:10,000 for the location of the city of Pilsen, and approx. 1:12,000 for Pardubice.

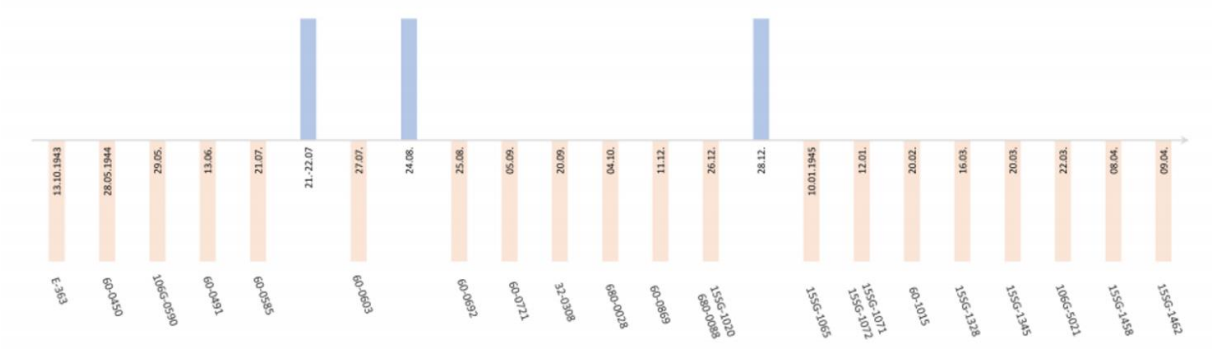

Figure 4. *Air raids against the city of Pardubice in 1944*

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2.3 Conditions at the time when the images were taken

The weather conditions at the time when the images were taken represent another important factor, and this factor may outweigh the time gap between the reconnaissance mission and the air raid. For example, the situation in Pardubice after the last air raid on December 28, 1944, when, in January 1945, the site was covered with a layer of snow, see Fig. 5.

From the reconnaissance images taken immediately after the raid, it is possible to interpret the immediate impact of the aerial bombing on the site. However, there may be a smoke-covered area in these images, which makes the evaluation impossible. The smoke cover of a large part of the evaluated locations is evident especially after successful air raids on industrial buildings, such as Fanto's plants in Pardubice and Škoda plants in Pilsen, see Fig. 6.

Figure 5. *Sample of airport and Fanto´s plants (today PARAMO refineries) in Pardubice, January 1945*

Figure 6. *Samples of reconnaissance missions one day after the air raids on Fanto's plants in Pardubice (August 25, 1944) and Škoda plants in Pilsen (April 26, 1945)*

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2.4 Interpreter's experience

The analysis and interpretation of the images must also include pre-raid images that provide important information about the situation before the air raid, thus excluding objects that are not related to the impact of the aircraft ammunition and could be misleading (e.g. man-made objects, which may be interchangeable with aircraft ammunition impact sites).

The probability of identifying the impact site of unexploded ammunition decreases with increasing time difference between the air raid and the reconnaissance mission. Despite the fact that the signs after the bombing and especially the craters after the so-called high-explosive bombs can be recognized even after a longer period of time and can determine the area as pyrotechnically risky, the identification of the site of impact of unexploded ammunition from the images is much more difficult. After a short period of time, identification can be more difficult due to the effects of human activity, weather and other aspects.

This research of the project is focused on the interpretation of unexploded ammunition sites identifiable from the images, but it must be said that in locations exposed to carpet bombing, the presence of unexploded ammunition cannot be ruled out. Furthermore, the place of impact of unexploded ammunition can be hidden under the material thrown up by a bomb that exploded nearby, or it can be shaded, etc. Using the procedure described in this project, i.e. interpretation of images from multiple time series, these effects are eliminated as much as possible.

It is also impossible to rule out or verify the possibility that unexploded bombs were defused immediately after the air raid or in the post-war years. Especially in case of strategically important buildings (industrial plants, infrastructure – railways, roads, airports, etc.), inhabited parts, etc., there was an effort to put the objects back into operation as quickly as possible. Fig. 7 and Fig. 8 document the repairs at Pardubice Airport, where you can see the situation one day after the second air raid (August 25, 1944) and six months after this air raid (February 20, 1945). Fig. 8 shows the repair process – in the lower left corner, there are accumulated piles of material that were thrown up when the bomb exploded, as well as already covered craters.

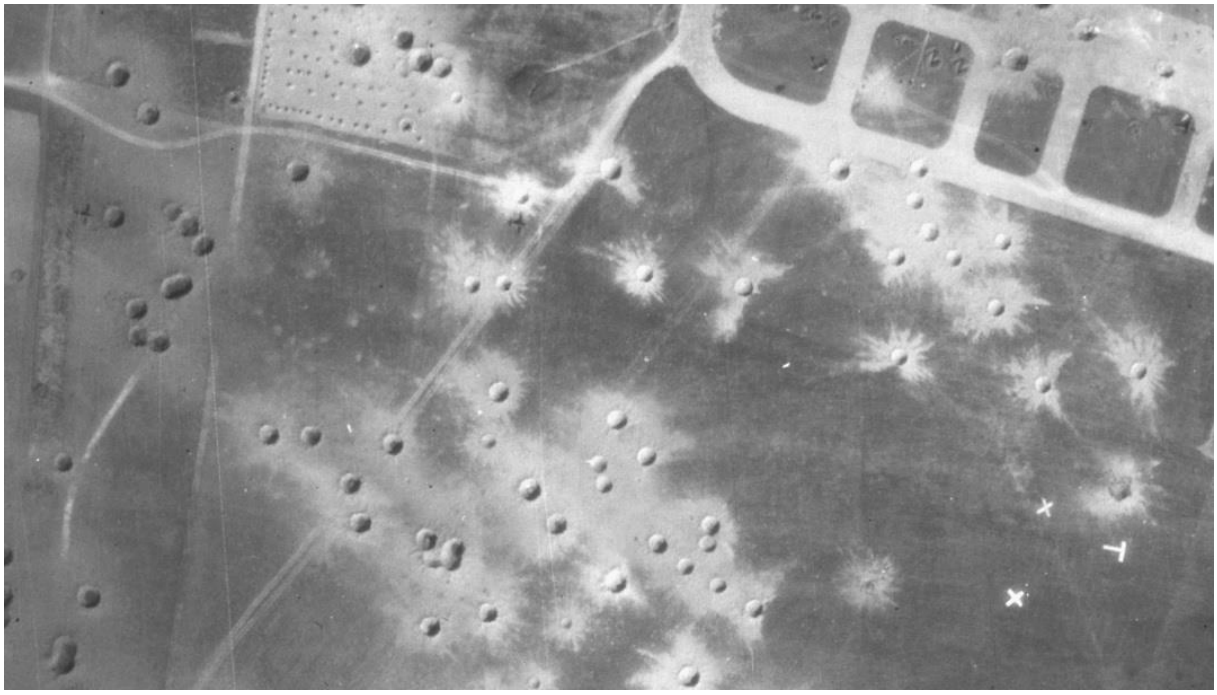

Figure 7. *Pardubice Airport August 25, 1944, one day after air raid*

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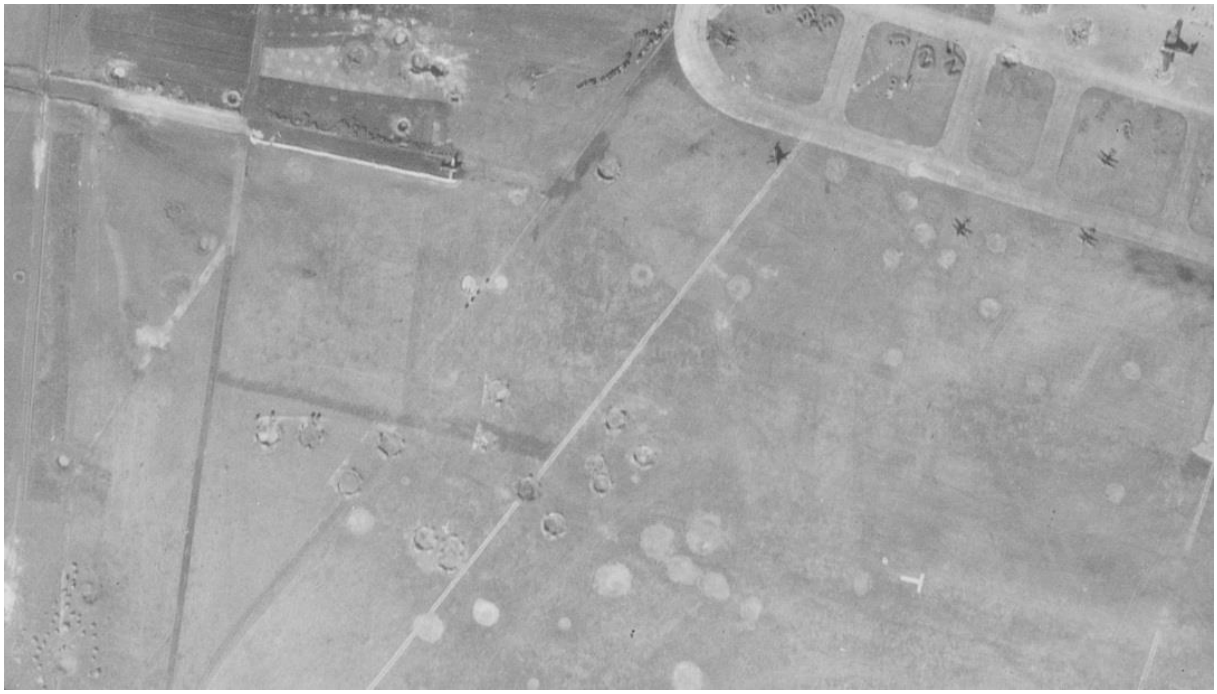

Figure 8. *Pardubice Airport February 20, 1945*

The interpreter must have several images of the evaluated area after each air raid, as well as images from various reconnaissance missions, which must be stereoscopically interpretable. Furthermore, the interpreter must be able to recognize different types of bombs and characteristic landscape features caused by their impact, must be able to identify and distinguish military objects (e.g. defensive positions, trenches, etc.) and the consequences of bombing (craters, damaged buildings, etc.) from non-war objects. In the area evaluation of the site, all available images are analyzed, and there is a possibility that some sites are evaluated as insufficiently covered.

It is also necessary to take into account the possible delay of the bomb fuse when interpreting the images, especially if the use of this type of bombs is indicated in the text documents related to the examined site.

Most ammunition found in the evaluated locations was equipped with a delay fuse in fractions of a second, but there were also bombs with a 2-144 hours delay fuse. In all cases, images with a larger time interval from the air raid, because of the detonation delay, were also included in the analysis.

In terms of the interpretation, the most problematic site was Pardubice Airport, where, according to archive documents, 1,178 500lb GP (so-called General Purpose) explosive bombs were used during the raid on August 24, 1944, as well as 1,026 of 100lb GP and 6156 of 20lb fragmentation bombs. Fragmentation bombs were used for their area effect, and the objective in this case was to damage as many aircraft, landing runways, etc. at the airport as possible. Due to the use of different calibres, it was not possible to determine from the images whether it was a site of unexploded ammunition or a small calibre bomb that had exploded.

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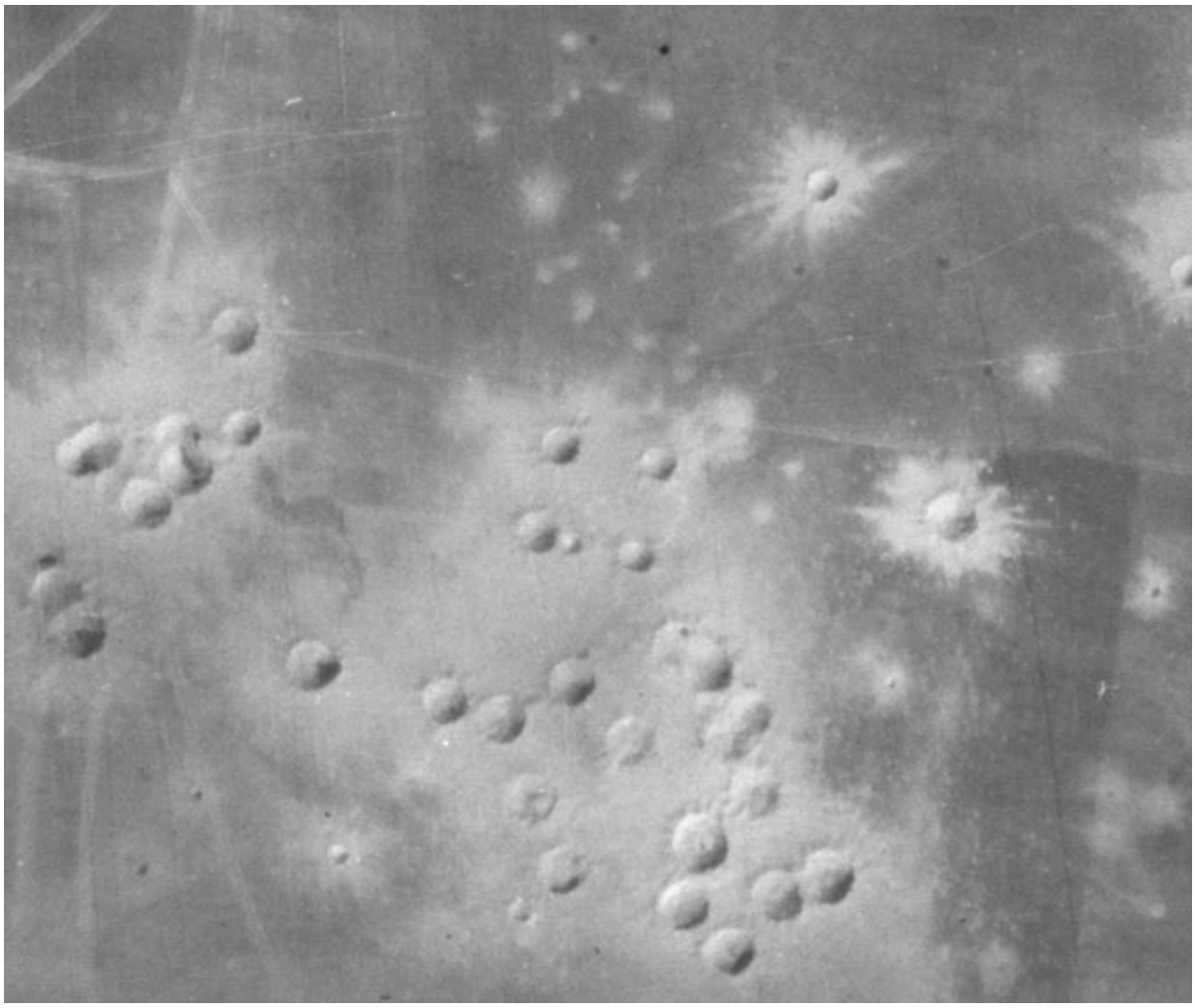

Figure 9. *Pardubice Airport August 25, 1944, use of different calibres of aircraft ammunition*

2.5 Stereoscopic evaluation

Each identified site of unexploded ammunition is always determined using at least two images. Wherever the data allowed, the potential finding is further confirmed using at least one more reconnaissance mission.

Stereoscopy was used in places of image pair overlaps as a necessary tool complementing 2D image analysis and confirming the results of the identification of the findings, where stereoscopic processing allows the identification of objects in 3D space, thus facilitating their clearer identification.

Image defects such as various impurities, dust, scratches, etc. represent a big problem when processing historical images, because they are easily interchangeable with real objects in the image. Most of these defects appear as small dark or bright spots that are easily mistaken with the point of impact of unexploded ammunition. The most effective way to distinguish these defects from real objects is through stereoscopic image evaluation. A method creating anaglyphs was used for the stereoscopic processing for the purposes of this project. It uses the so-called radiometric image separation to create 3D perception, where two planar projections of a 3D object are broken into colour components, separately for the left and right eye (the so-called cyan). The location of the image pair overlap shown in this way (shot of the same place from different angles) creates spatial perception using special glasses with colour filters, known as anaglyphic glasses. A procedure scheme of the anaglyph formation is shown in Fig. 10.

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Fig. 11 shows part of an anaglyph created from images 4301 and 4302 from the mission 104W_167C from April 26, 1945, which shows the situation around today's U Prazdroje Street the day after the last air raid against the city of Pilsen.

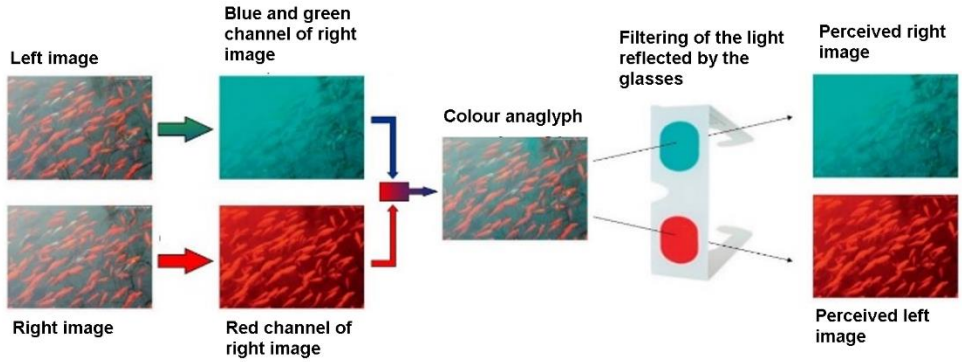

Figure 10. *Anaglyph formation diagram*

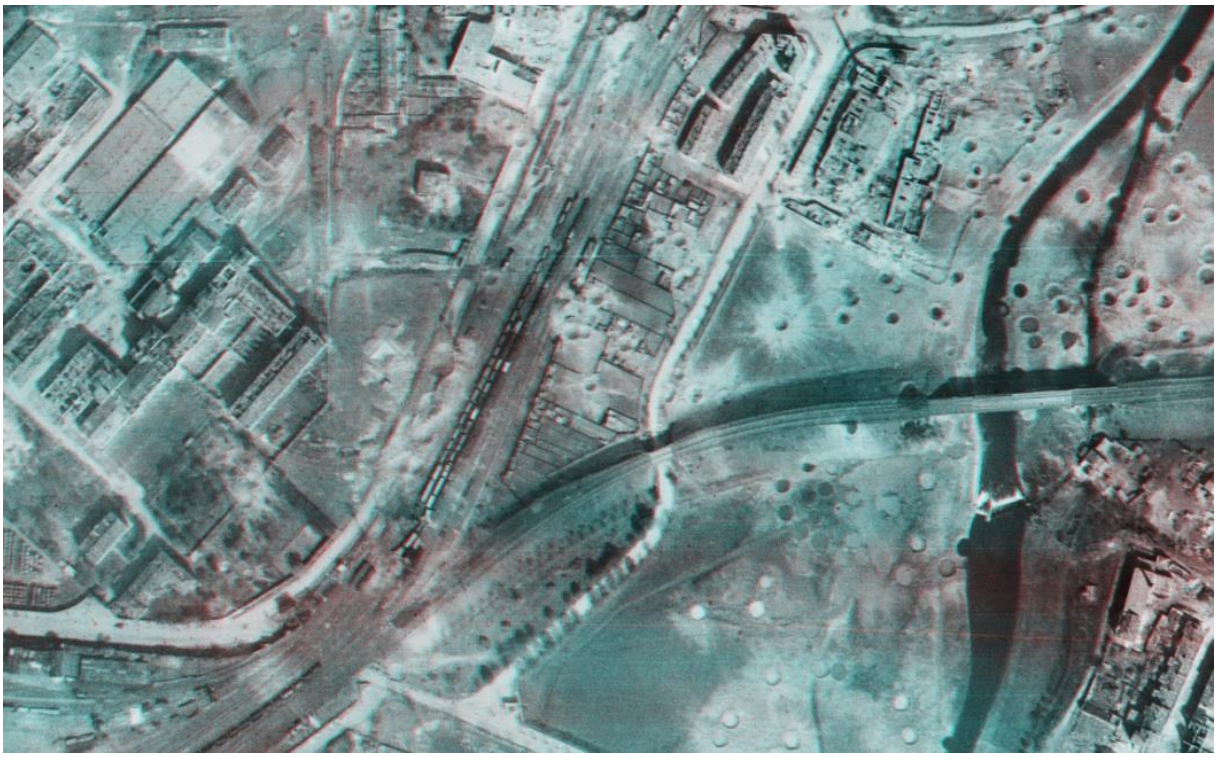

Figure 11. *Example of an anaglyph from the surroundings of today's U Prazdroje Street in Pilsen*

2.6 Interpretation samples

The examples in Figs. 12 and 13 illustrate the procedure used to identify the unexploded ammunition sites from the evaluation of images from multiple time series in the location of Pilsen. The first example from Pod Vrchem Street shows that the finding is the result of the last air raids on Pilsen in April 1945. The second example from the football field near Luční Street shows the situation before the air raids in 1944, as well as mission 31_4866, where the already covered crater from the air raids in 1944 (marked in blue) and the state after the air raids in April 1945 are visible. Two unexploded ammunition sites have been identified here.

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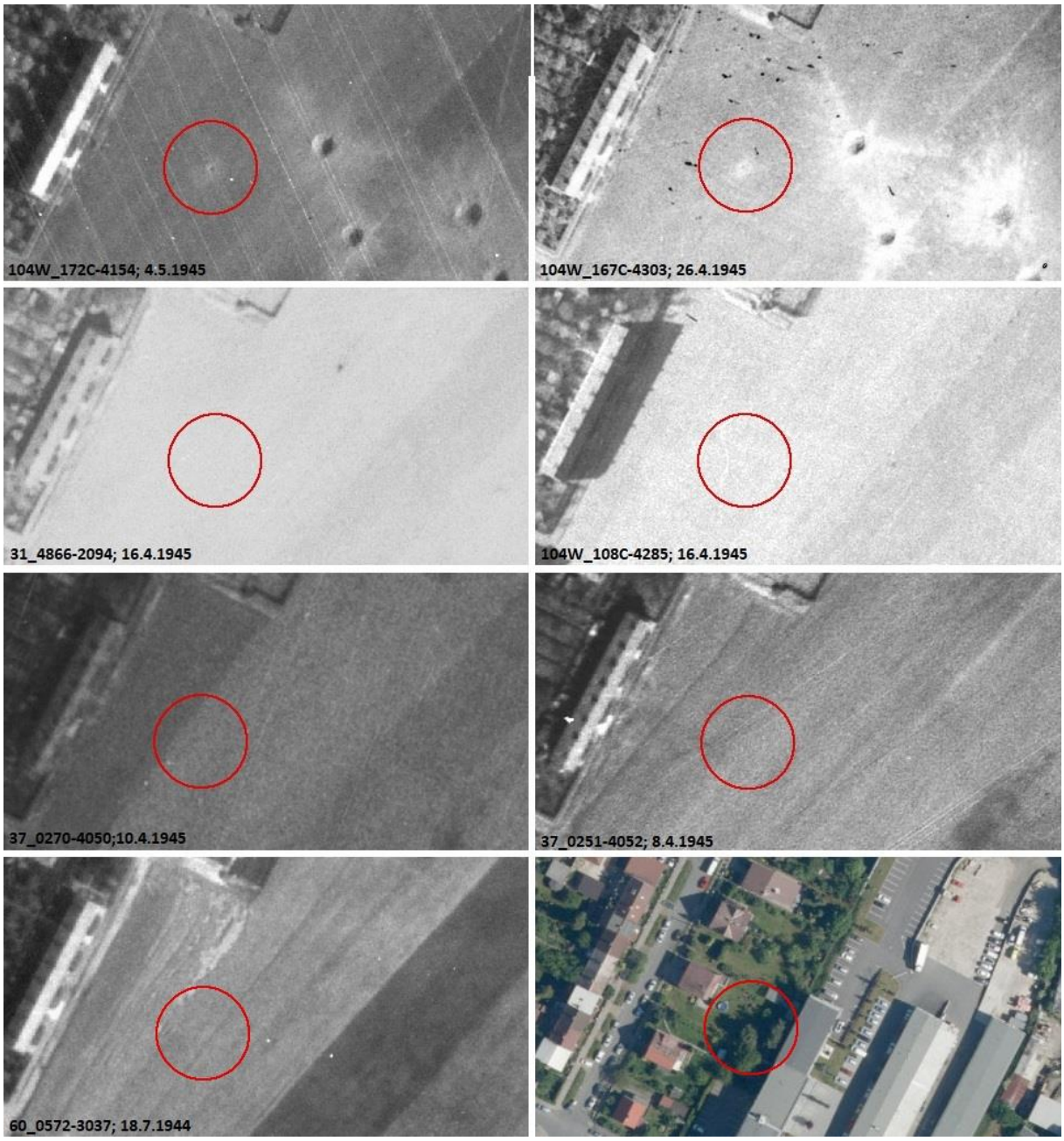

Figure 12. *Image evaluation from multiple time series*

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Figure 13. *Image evaluation from multiple time series*

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The examples in Figs. 14 and 15 show cases of serial drops of General Purpose bombs in Pardubice. The identified sites of unexploded ammunition are marked in red. In areas that were not exposed to carpet bombing, it is possible to recognize a serial pattern of ammunition drops from a single aircraft. It is also possible to presume other possible sites of ammunition impact from the uneven spacing of the craters.

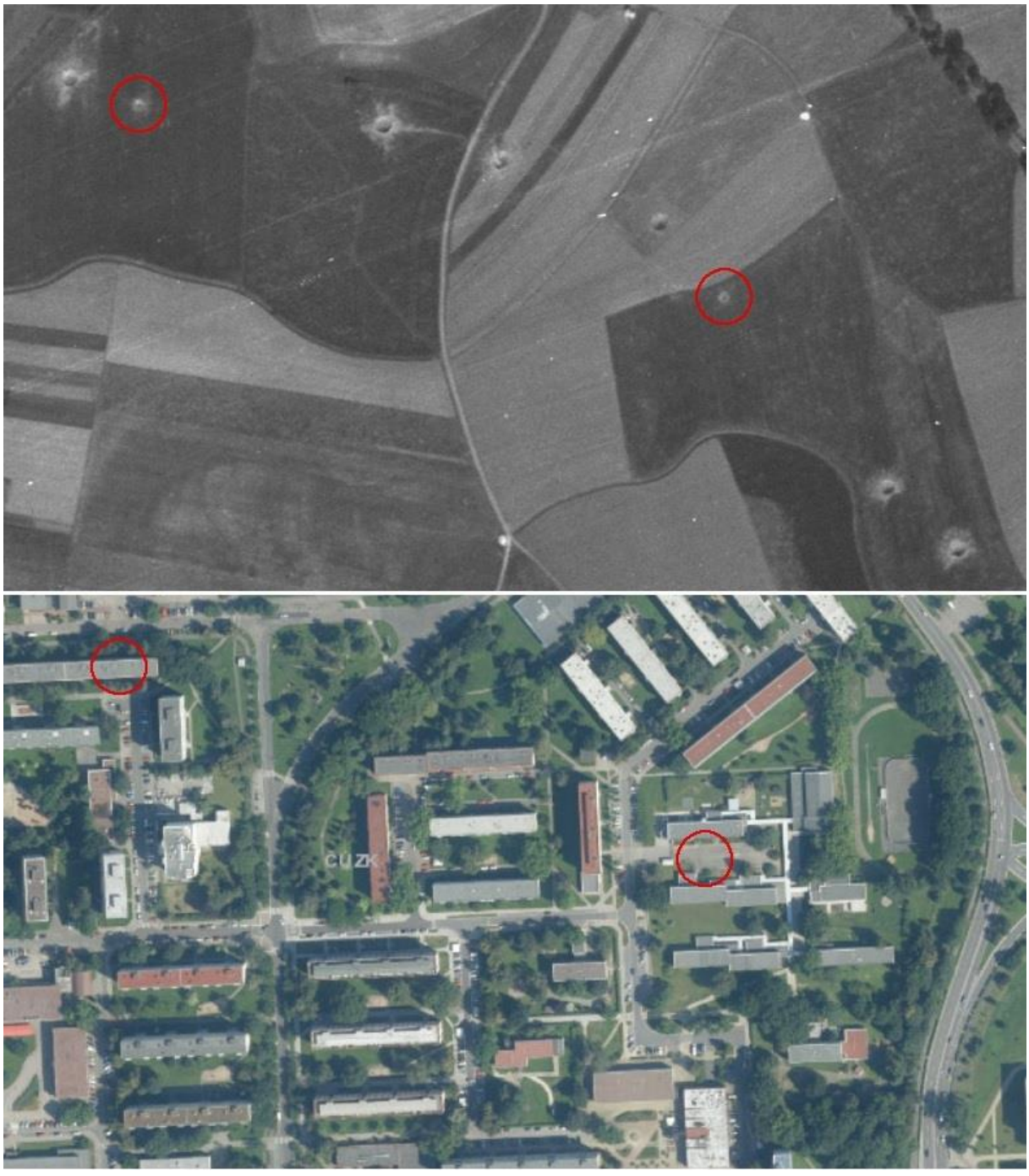

Figure 14. *Serial drop of high-explosive bombs – comparison with the present state*

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Figure 15. *Serial drop of high-explosive bombs – comparison with the present state*

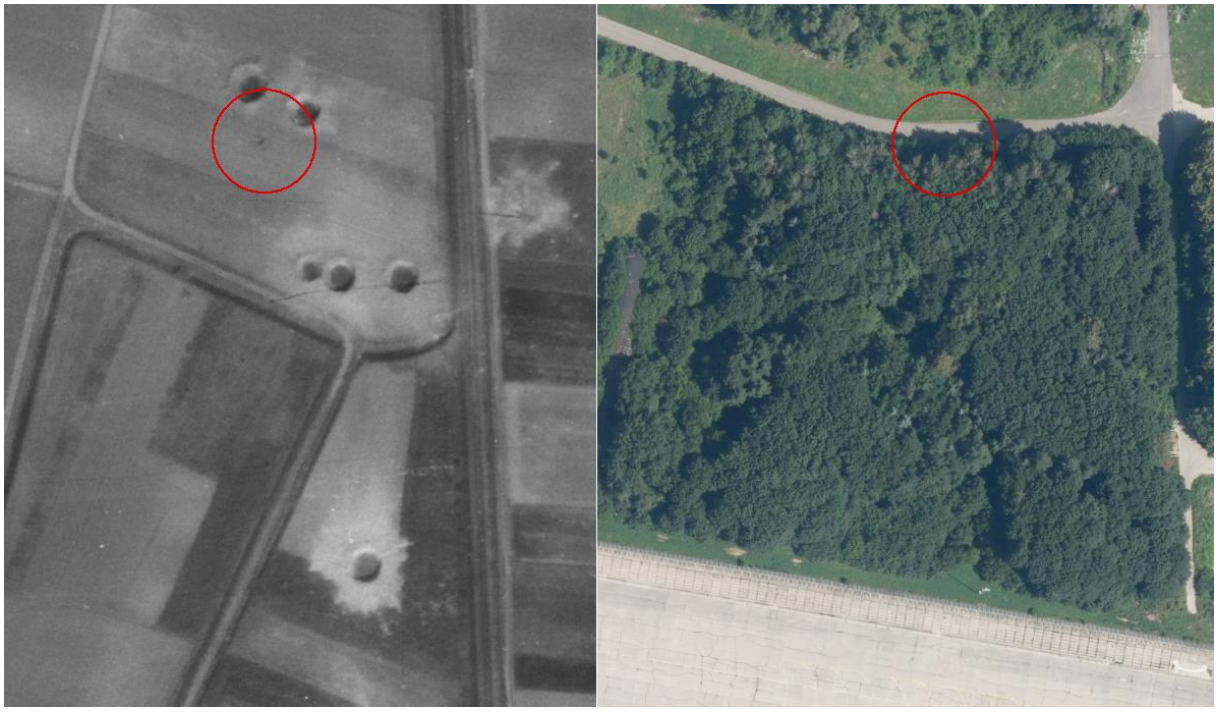

Figure 16. *Finding – comparison with the present state*

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Figs. 17 and 18 show examples of defects in the images (marked in green), where there is a risk of confusion with an unexploded ammunition site (marked in red).

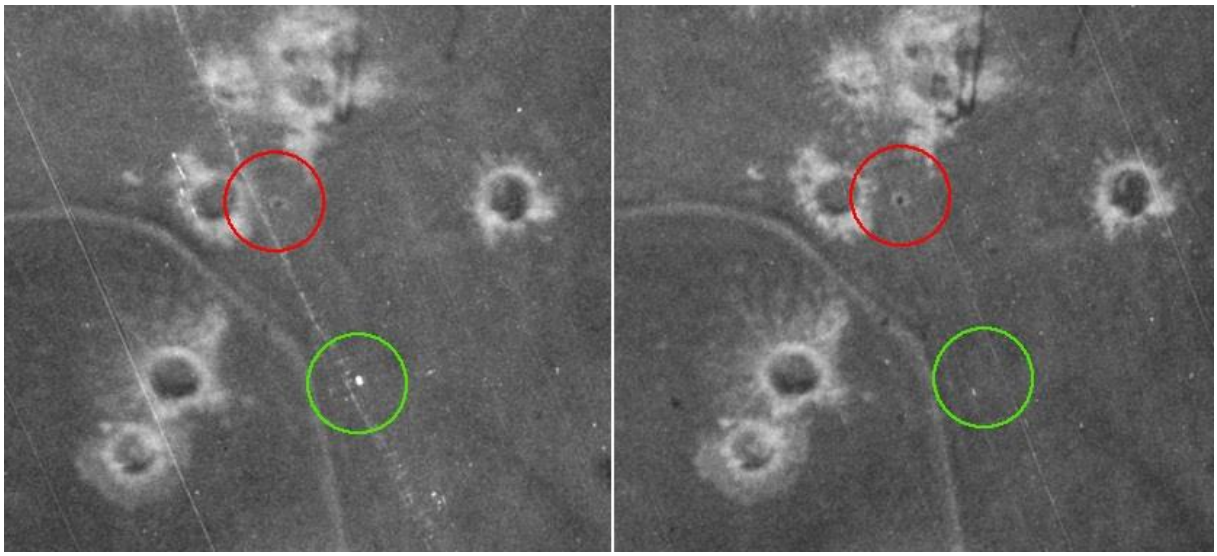

Figure 17. *Examples of defects in images (marked in green)*

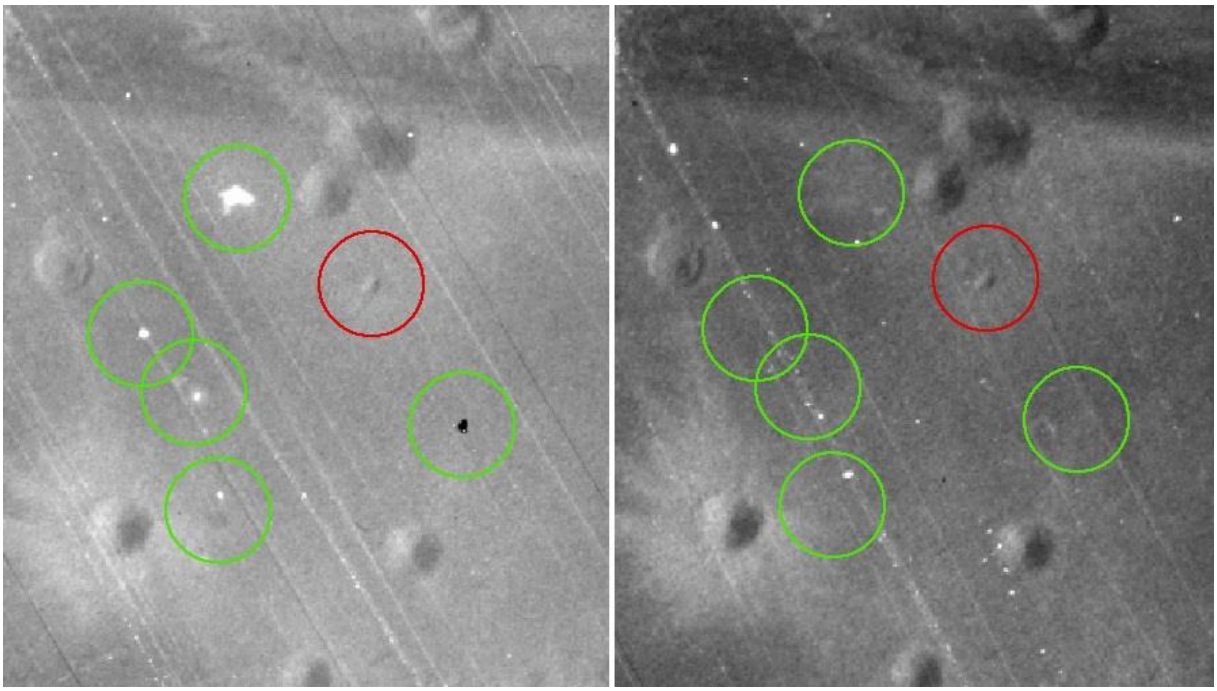

Figure 18. *Examples of defects in images (marked in green)*

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2.7 Preparation of materials for field work – control excavations

In total, documents for 32 identified unexploded ammunition sites in the city of Pardubice were prepared for the field work. There were also 61 sites in Pilsen.

The documents for field work also include a spatial database in the format of shp and kml. This database contains a unique finding ID, mission and image number, XY coordinates in S-JTSK, topographical image documentation number and work priority designation. A list of coordinates in xls format, and image documentation for the individual findings in jpg and pdf format are included as well. All data are linked using a unique ID of the identified unexploded ammunition site.

3 CONCLUSION

The described procedure corresponds to the requirements for the identification of the sites where unexploded aircraft ammunition can be found. However, it does not work with aerial survey images, but with images from reconnaissance flights. Their quality is far worse compared to current orthophoto images, and the image overlaps do not meet the current requirements.

This procedure is followed by the actual site pyrotechnic survey. Based on the performed pyrotechnic work, we can already state that some sites have confirmed the presence of ferromagnetic substances (iron). The actual finding of aircraft ammunition can only be confirmed by a control excavation, which entails relatively complex and demanding security measures. The finding of such ammunition is hindered by the fact that there is no information about the disposal of unexploded ammunition during and after World War II. The disposal was carried out in most bombing sites, but occasional findings indicate that not all unexploded bombs have been removed.

LIST OF ABBREVIATIONS

AFHRA	**A**ir **F**orce **H**istorical **R**esearch **A**gency
USAAF	**U**nited **S**tates **A**rmy **A**ir **F**orces
TNA	**T**he **N**ational **A**rchives
RAF	**R**oyal **A**ir **F**orce
BG	**B**ombardment **G**roup
GP	**G**eneral **P**urpose
RDX	**R**esearch **D**epartment **Ex**plosive
MVČR	**M**inistry of the **I**nterior of the **C**zech **R**epublic
S-JTSK	**S**ystem - **U**nified **T**rigonometric **C**adastral **N**etworks

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