DISPLAYS OF HARD COAL DEEP MINING IN AERIAL PHOTOS

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ABSTRACT

Deep hard coal mining manifests itself in the landscape in a specific way: primarily through anthropogenic landforms and secondarily through land cover changes not directly related to mining activity. A majority of these displays can be interpreted using aerial photos. Multitemporal data then make it possible to analyse the development of identified displays. However, correct interpretation is based on a profound acquaintance with the displays of deep coal mining in aerial photos. This article focuses on the identification of primary and secondary displays of deep hard coal mining in aerial photos as well as the interpretation of elementary landscape processes that are conditioned by mining.

Key words: visual photointerpretation, aerial photo, anthropogenic landforms, landscape changes, Ostrava-Karviná Mining District

1. Introduction

Aerial photos represent a significant data source of ongoing landscape transformation with regard to relatively high dynamics of anthropogenically conditioned landscape changes in hard coal deep mining areas. The study of quality photos of mining displays in the landscape is based on the principles of visual photointerpretation the aim of which is to identify individual objects and assess their importance (Jensen 2006). Aerial photointerpretation starts from visual perception of the objects of the outer world (Ciolkosz, Miszalski, Oledzki 1999).

The principles of photointerpretation have been developing on the basis of empirical experience for more than 150 years (Jensen 2006).

Visual aspect and character of objects in images are identified and described using interpretation criteria (Čapek 1978; Ciolkosz, Miszalski, Oledzki 1999; Pavelka 1999; Jensen 2006). Elementary interpretation criteria include location, tone and colour, size, shape, texture, structure, shade, height and depth, gradient, appearance, position and connection. Relationship between the appearance of an object in an image and its appearance in a moment of ground observation is expressed by means of a photointerpretation key (Čapek 1978). Correct interpretation is thus always dependent on the interpreter's experience.

The photointerpretation key is necessary for the correct evaluation of the content of an aerial photo. Its importance increases when interpreting photos of areas with specific displays of the landscape configuration and with the high dynamics of ongoing landscape changes. The aim of this article is to characterize so far unpublished displays of hard coal deep mining in aerial photos using the example landscape of Ostrava-Karviná Mining District (OKMD). This study will therefore help interpret aerial photos of the areas of deep mining for the purpose of the evaluation of landscape changes and landscape processes, identification of anthropogenic landforms and its multitemporal changes, etc.

Displays of deep hard coal mining on the ground surface comprise specific anthropogenic landforms directly connected with mining. The very mining-related landforms include: deep coal mines, waste banks and tailings ponds (Kirchner, Smolová 2010). Other related accompanying landforms occurring in the landscape are e.g. ground subsidences, manipulation areas, reclamation areas or road and rail embankments. Landforms related to the mining of fossil fuels including excavation, levelling and accumulation activities are, in all the cases, results of secondary processes as they are not intended to be the goal of mining but only its by-products (Szabó, David, Loczy 2010). Under given climatic conditions, the processes of natural denudation produce secondary (semi-anthropogenic or natural-anthropogenic) landforms on these newly developed surfaces.

Subsequent subsurface coal mining accelerates landscape processes that can be identified in aerial photos on the basis of land cover changes as, for instance, in the case of abandonment (urban fabric changing into semi-natural areas) or water body emergence that manifests itself mainly in the formation of submerged ground subsidences.

2. Study area and methods

In this study, displays of deep hard coal mining in aerial photos are presented on the area of the Ostrava-Karvi-

To be quoted as:
Mulková, M. – Popelková, R. (2013): Displays of hard coal deep mining in aerial photos
AUC Geographica, 48, No. 1, pp. 25–39

ná Mining District (Figure 1). The Ostrava-Karviná Mining District (OKMD) is a major hard coal district in the Czech Republic representing the southern part of the Upper Silesian Coal Basin, a larger part of which occupies neighbouring Poland. From the point of view of geology, it is formed by the Ostravian part comprising Ostrava and Orlová Basins and the Karviná part. Outside of our interest area lies the Beskydian part of the OKMD where coal mining practices have so far been taking place to a limited extent (Machač, Langrová a kol. 2003). In the 1850s the Ostrava and Karviná regions turned into areas to industrialize rapidly thanks to high-quality black coal deposits. One-time agrarian regions gradually changed into industrial areas dominated by mining, metallurgic and chemical industries. All these activities, particularly coal mining, had a considerable effect on the Ostrava and Karviná landscape character.

The displays of deep coal mining in the landscape were detected using contact copies of archive black-and-white aerial photos from the period of 1947 to 1995 (provided by the Military Geography and Hydrometeorology Office in Dobruška) and a coloured orthophoto from 2003 and 2009 (map service of the Portal of the Public Administration of the Czech Republic). Scanned aerial photos were transformed into the S-JTSK coordinate system using polynomial transformation in the PCI Geomatica V10.3 software. Landforms was identified by means of visual photointerpretation of aerial photos in the ArcGIS 10 software. Landscape analysis was further used to determine processes (pressures) within the study area and theirs displays in aerial photos (Mulková, Popelková, Popelka 2010).

3. The displays of deep hard coal mining

Displays of deep hard coal mining interpreted on the basis of aerial photos have been divided into two basic groups:

- primary displays of deep hard coal mining: waste banks, ground subsidences, tailings ponds, manipulation areas and mine buildings and structures,
- secondary displays of deep hard coal mining: reclamation areas, dry tailings ponds, road and rail networks and vegetation-free areas.

Other deep mining related processes presented in this study include abandonment, forestation and water body formation.

3.1 Primary displays of hard coal deep mining

Primary displays of hard coal deep mining are represented in aerial photos by anthropogenic landforms directly related to mining practices. These include post-mining landforms (waste banks, ground subsidences) and industrial landforms (tailings ponds, manipulation areas).

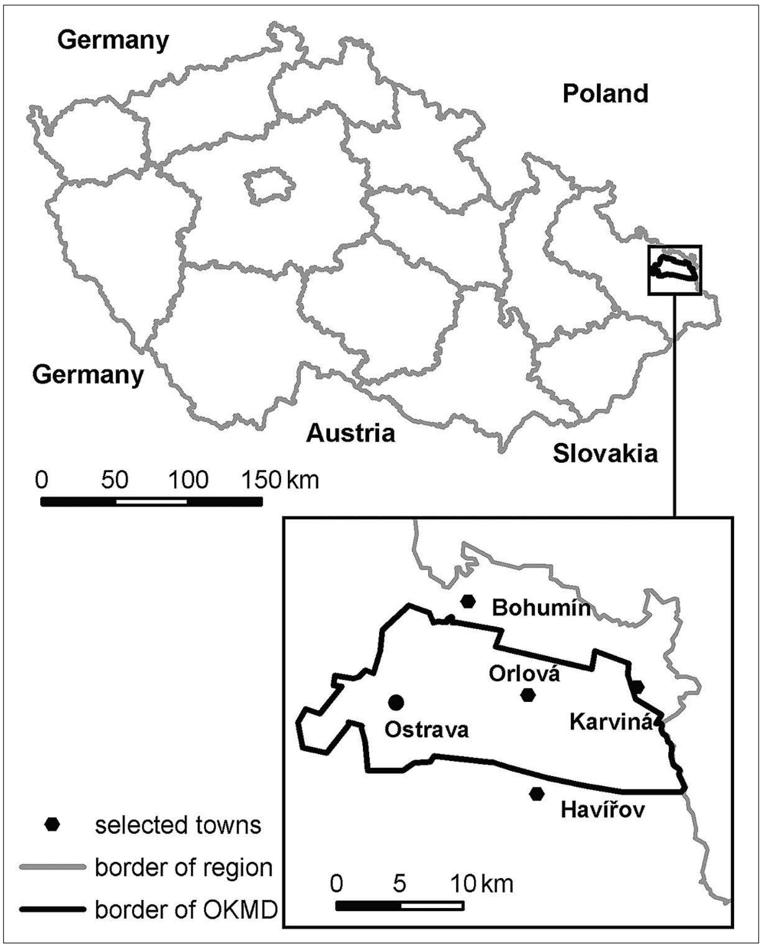


Fig. 1 Localization of the Ostrava-Karviná Mining District (OKMD) within the Czech Republic

Areas of subsurface mining can as well be identified, namely based on the presence of mine buildings and structures.

3.1.1 Waste banks

Waste banks are convex landforms whose area can reach from a few areas to tens of hectares (Havrlant 1980). They originate as a result of the deposition of extracted coal waste during deep coal mining. The OKMD area includes the following basic types of waste banks (Havrlant 1980): cone-shaped waste banks, waste piles, plate-shaped waste banks, terrace-like waste banks, flat waste piles or their combinations. Processes of natural geomorphological evolution on waste banks are faster than geological erosion in the area (Szabó, David, Loczy 2010). Geomorphological evolution is closely correlated with waste bank material, weather changes, slope gradient and vegetation cover. In some cases spontaneous ignition of deposited waste bank material is observed along with self-sustaining combustion. Losses in the volume of the burnt-out material result in further subsidence and mass movements (Szabó, David, Loczy 2010).

Active waste banks in the photos represent vegetation-free surfaces with clearly visible contours (Figure 2). They are generally found in the proximity of mine buildings.

Waste banks can be reclaimed after waste piling is terminated (Figure 3).

Waste banks characterised by self-sustaining combustion can best be identified in colour aerial photos in which the original black colour of waste bank surface is red (colour appendix Figure 18). This colouring is due to the conversion of clayey sediments due to high temperatures during combustion.

Fig. 2 (a, b) Waste banks in (a) an aerial photo from 1947 in Karviná-Doly mining area (© MO ČR/GeoSI AČR) and (b) an aerial photo from 2009 in Lazy mining area (© GEODIS BRNO, spol. s r. o.)

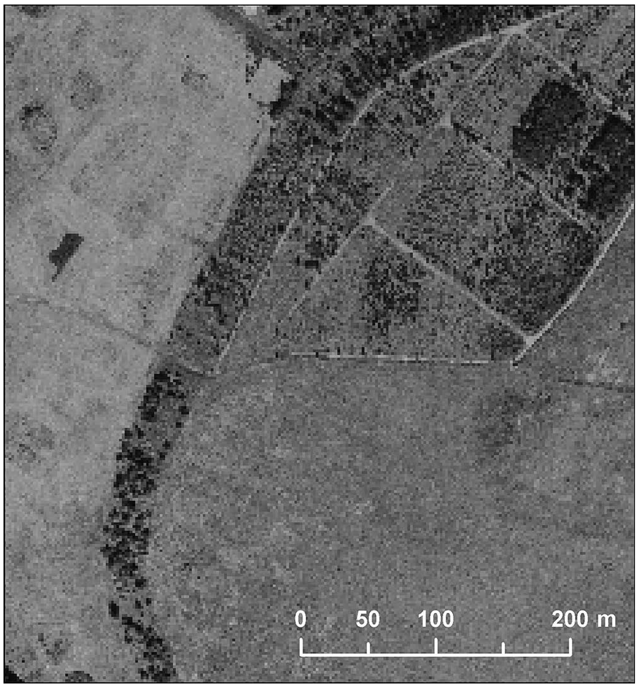


Fig. 3 The part of reclaimed Hohenegger waste bank in Lazy mining area and Karviná-Doly mining area in an aerial photo from 2003 (© GEODIS BRNO, spol. s r. o.)

3.1.2 Ground subsidences

Ground subsidences originate as a result of surface subsidence above mined-out space (Demek 1988). It concerns flat subsidences whose size depends on geological conditions, tectonics and the area and thickness of coal seams (Havrlant 1980). The subsidences can be filled with water. Submerged ground subsidences are displays of unfavourable disturbance of the regime of surface and subsurface waters the level of which has infiltrated above the bottom of subsided terrain (Zapletal 1969).

The extent of ground subsidence can best be determined on the basis of the photogrammetric evaluation of stereoscopic pairs of photos, radar interferometry and laserscanning. Clear-cut visual interpretation is particularly that of submerged ground subsidences that represent secondary mining displays and largely participate in the formation of water bodies. Unlike other water surfaces, they usually have an irregular broken shape (Figure 4, colour appendix Figure 24). It is changes in the shape and extent of water surfaces that can generally be observed when interpreting multitemporal aerial photos. Submerged ground subsidences positively affect ecological value of landscape as they increase species diversity of the territory. The banks of submerged ground subsidences provide favourable environment for wetland plant species as well as important animal species such as rare

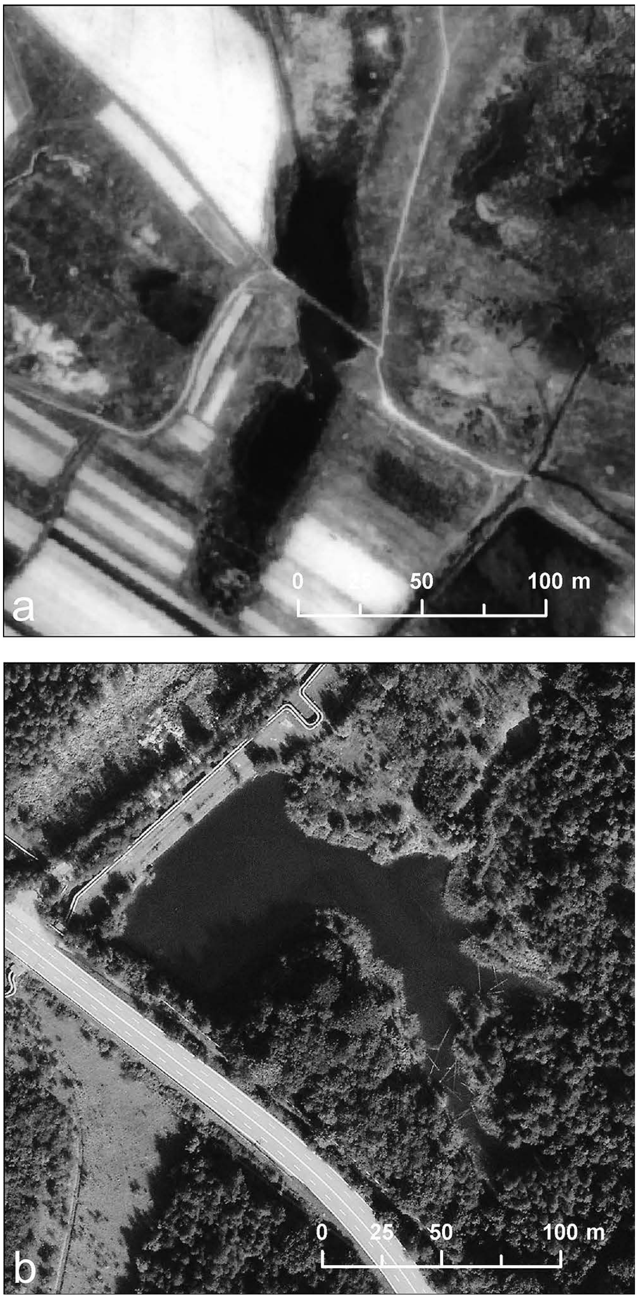


Fig. 4 (a, b) Submerged ground subsidences (a) in an aerial photo from 1947 (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.) in Karviná-Doly mining area

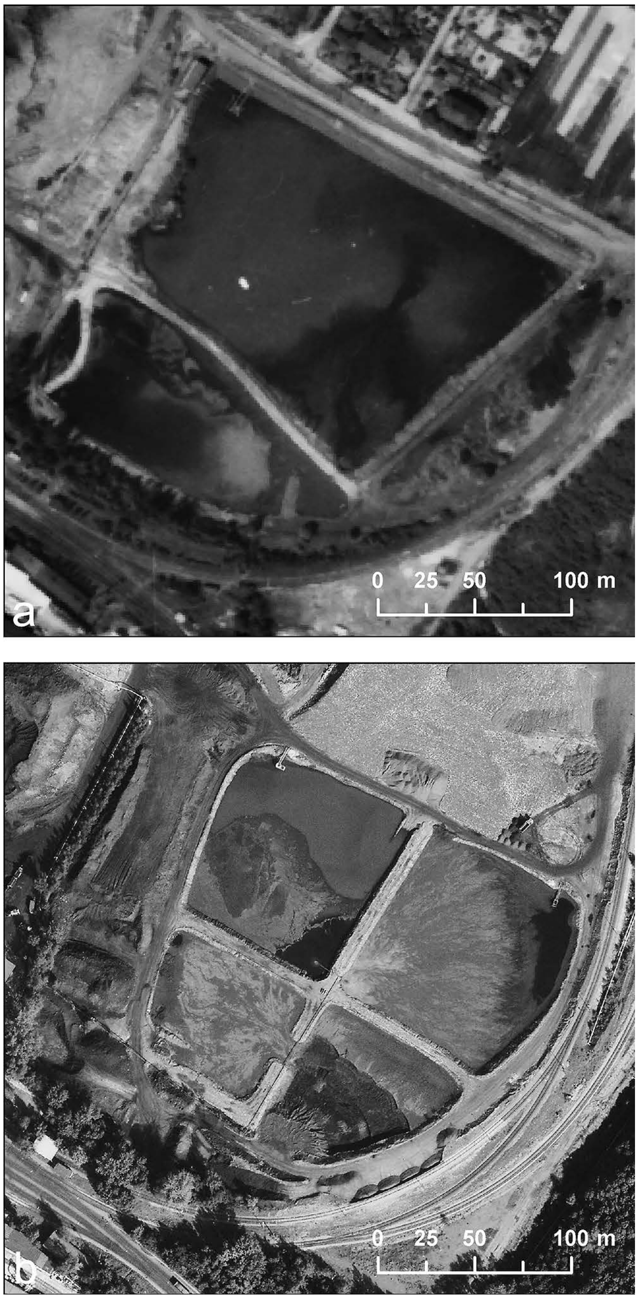


Fig. 5 (a, b) Tailings ponds in Lazy mining area in (a) an aerial photo from 1971(© MO ČR/GeoSI AČR) and (b) an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

invertebrates (e.g. specially protected dragonflies, crayfishes and shells) (Dolný, Ďuriš 2001).

3.1.3 Tailings ponds

The tailings pond, a natural or excavated basin, serves for permanent or temporary storing of hydraulically transported tailings (Kirchner, Smolová 2010). Hard coal deep mining area includes a few types of such ponds: flotation tailing ponds, coal ash ponds, coal sludge ponds and final sedimentation ponds. It particularly concerns water surfaces of a regular, often geometric, shape in the proximity of mine buildings (Figure 5, colour appendix Figure 22).

Final sedimentation ponds can have a character of natural water surfaces, which makes their interpretation in aerial photos difficult (Figure 6). As for problematic cases, clear-cut interpretation is possible making use of supporting data (the information about the sludge management of the mine).

3.1.4 Manipulation areas

Manipulation areas that are generally found in the proximity of mine buildings, tailings ponds or waste banks are anthropogenic levels and terraces of various shapes and sizes including access roads. They are detected in aerial photos as bare surfaces, either convex or concave, serving as manipulation areas for e.g. transport (Figure 7).

3.1.5 Mine buildings

Individual mine buildings including winding towers and other mining-related buildings can be identified in aerial photos (Figure 8, colour appendix Figure 23).

Fig. 6 Final sedimentation pond in Lazy mining area in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

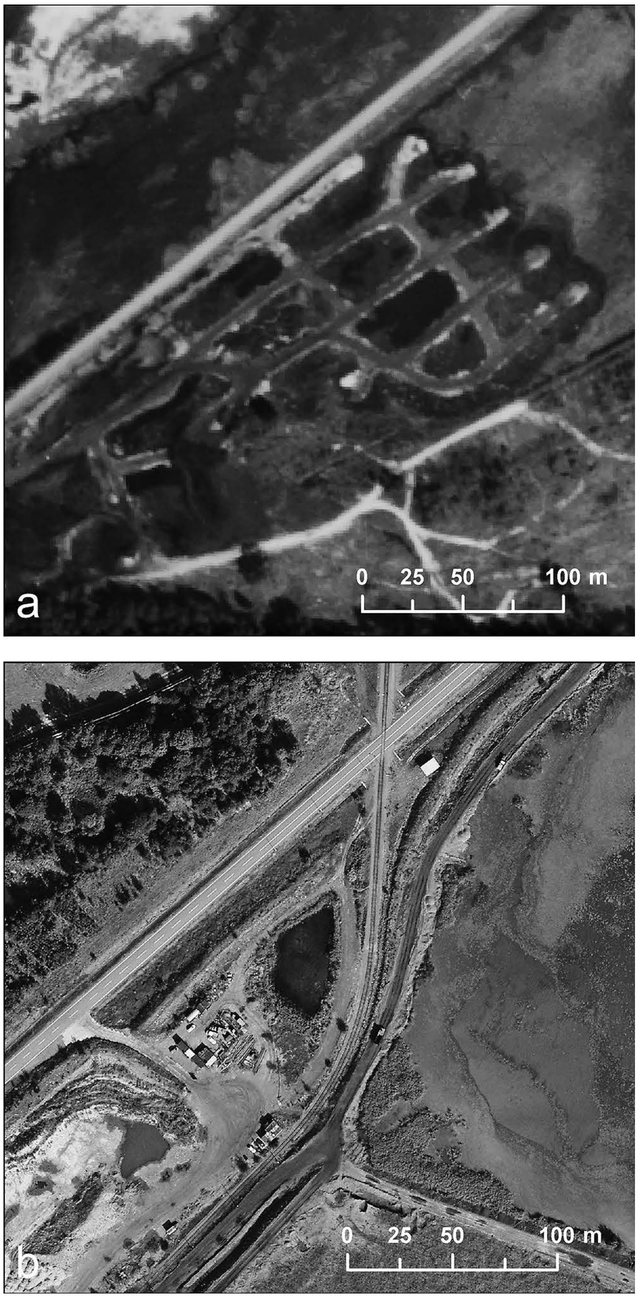


Fig. 7 (a, b) Manipulation areas (a) in an aerial photo from 1971 (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

They include temporary buildings that are renovated after the termination of mining practices. For example, the area of the ČSA 3 Mine (Jindřich Pit), which is visible in aerial photos from 1971 in the western part of the Karviná-Doly I Allotment, was covered with soil and grassed after the demolition of buildings. The contemporary orthophoto shows trees, scrub and herbaceous vegetation associations in this area. What points to one-time mining activities in this area are the foundations of old mine buildings that are visible in the orthophoto (Figure 9).

3.2 Secondary displays of deep hard coal mining

Secondary displays of deep hard coal mining identified in aerial photos include anthropogenic landforms that are not directly related to mining practices, particularly reclamation areas, dry tailings ponds and communication landforms.

3.2.1 Reclamation areas

Reclamation areas, which make up a component of reclamation construction sites, are characterised by temporary convex landforms in a shape of low flat waste banks (Figure 10). These should be levelled with the surrounding landscape after the termination of reclamation works. Reclamation areas are created in order to deal with negative effects of hard coal deep mining. The photos facilitate easy interpretation of new reclamation areas in the form of bare surfaces. Unlike waste banks, reclama-

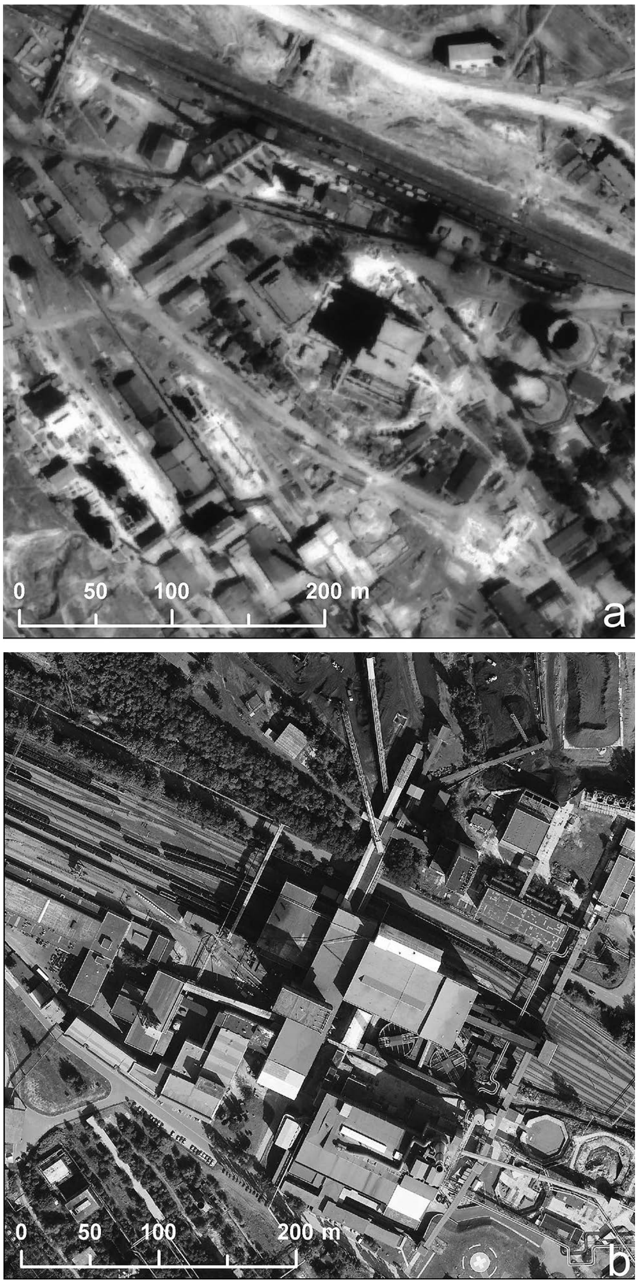


Fig. 8 (a, b) Mine buildings (a) in an aerial photo from 1947 (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

Fig. 9 (a, b) Area of the ČSA (a) in an aerial photo from 1971 (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 2003 (© GEODIS BRNO, spol. s r. o.)

tion areas can be found relatively far from mine buildings. In many cases, visual photointerpretation needs to be carried out with the use of supporting data (the maps of the reclamation construction sites, documentation of reclamation etc.) in order to avoid confusion with waste banks.

3.2.2 Dry tailings ponds

These are shallow concave vegetation-free landforms that appear in the landscape after the termination of sludge management activities. Filled tailings ponds dry out and if no reclamation is carried out, they gradually overgrow with self-seeded vegetation.

Dry tailings ponds can be identified in aerial photos on the basis of their shape that usually remains preserved after the life of the ponds has come to the end (Figure 11). Clear-cut interpretation is facilitated by the comparison of time series of aerial photos.

3.2.3 Communication landforms

If some areas have been undermined, embankments are created to level surface deformations that damage communications. High embankments of up to a few meters are built due to the modification of the roads. The types of embankments that manifest themselves as lines and are easily identifiable in aerial photos involve railway and road embankments as well as embankments of engineering networks (Figure 12, colour appendix Figure 25).

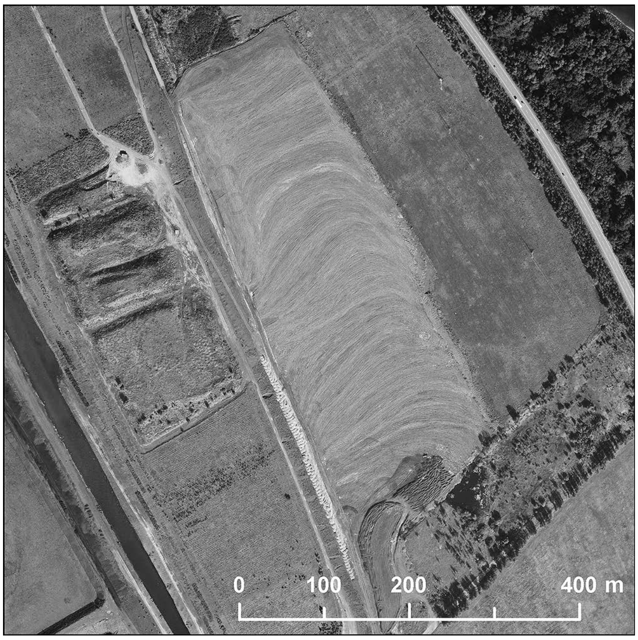


Fig. 10 Reclamation areas in Louky mining area in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

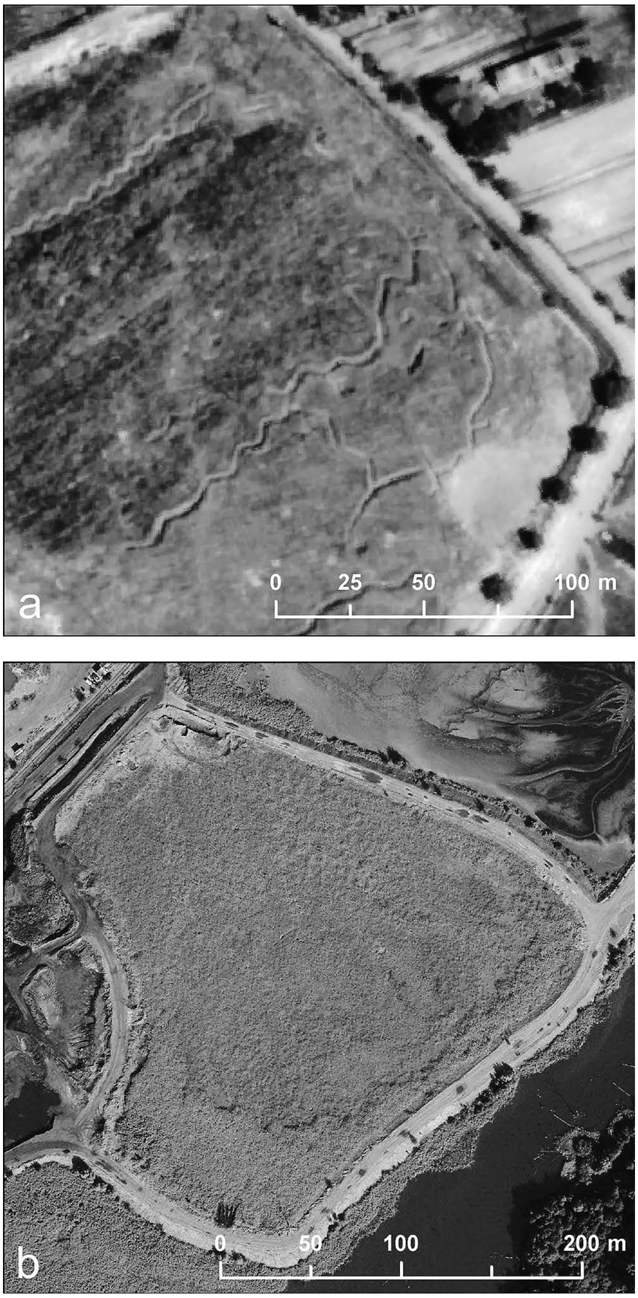


Fig. 11 (a, b) Dry tailings ponds (a) in an aerial photo from 1947 (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

3.2.4 Vegetation-free surfaces

Vegetation-free surfaces are most often related to bare surfaces appearing particularly after the demolition of buildings (Figure 13). Their duration is relatively short as they gradually overgrow with self-seeded vegetation.

4. Processes related to deep mining

Time series of aerial photos make it possible to observe landscape changes on the basis of ongoing processes that can be visually interpreted indirectly from land cover changes. The most frequent mining-related processes involve submergence and abandonment that can consequently lead to the process of forestation.

4.1 Abandonment

As based on multitemporal aerial photos, the process of abandonment can be identified at places where artificial surfaces, agricultural areas, forests or water bodies turn into semi-natural areas of trees, scrub and/or herbaceous vegetation associations (Figure 14, colour appendix Figure 21).

Undermining, which is accompanied by land surface deformations, generally leads to the disturbance of the structural mechanics of buildings and consequently to their demolition. The photos clearly show a visible decrease in the build-up area and its gradual overgrowth by self-seeded vegetation. A typical example is the Church of St. Peter of Alcantara in the northern part of the Karviná-Doly II Allotment (Figure 15). Due to mining practices in the area, the church subsided by 36 m (Popelková 2009).

Fig. 12 Railway embankment in Lazy mining area in an aerial photo from 2009 (© GEODIS BRNO, spol. s r. o.)

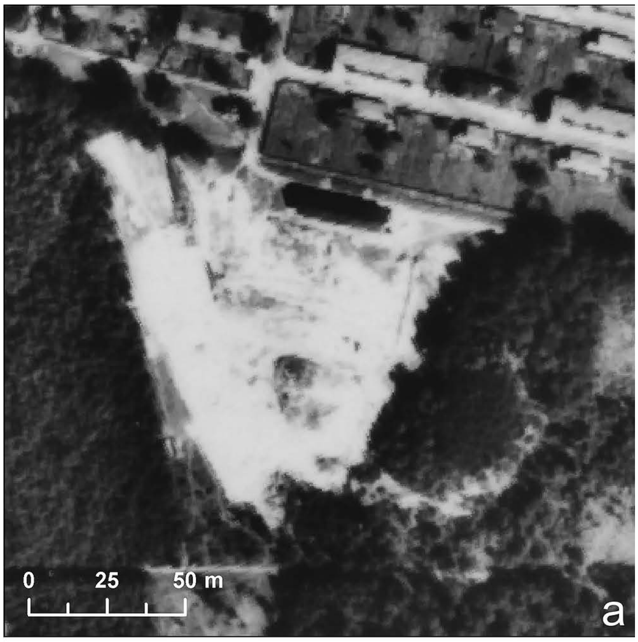


Fig. 13 (a, b) Vegetation-free surfaces (a) in an aerial photo from 1947 in Karviná-Doly mining area (© MO ČR/GeoSI AČR) and (b) in an aerial photo from 1995 in Lazy mining area (© ARGUS GEO SYSTEM 1995)

All buildings in the proximity of the church have been demolished. A submerged ground subsidence is found to the east of the church (Figure 16).

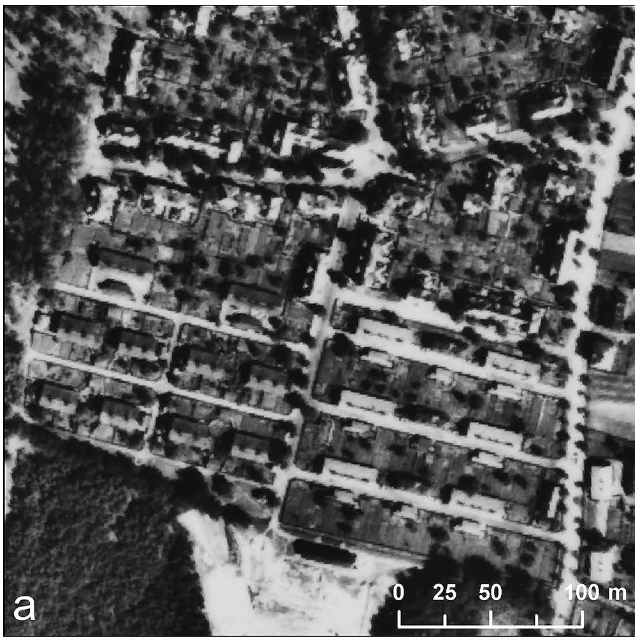
Aerial photos also help to identify the process of abandonment in originally agricultural areas which gradually turn into semi-natural areas as a result of being disused.

4.2 Forestation

In most cases, the process of abandonment is succeeded by the process of forestation in which abandoned areas overgrow with self-seeded vegetation in the first phase followed by a subsequent gradual transition to forest stands.

4.3 Submersion

Submersion represents a process of the change of artificial surfaces, agricultural areas, forests and semi-natural areas into water bodies. New water surfaces originate primarily in a close relation to mining (tailings ponds) or secondarily as a consequence of undermining (submerged ground subsidences). Aerial photo time series facilitate the identification of the process from both spatial and temporal points of view (Figure 17, colour appendix Figure 20).



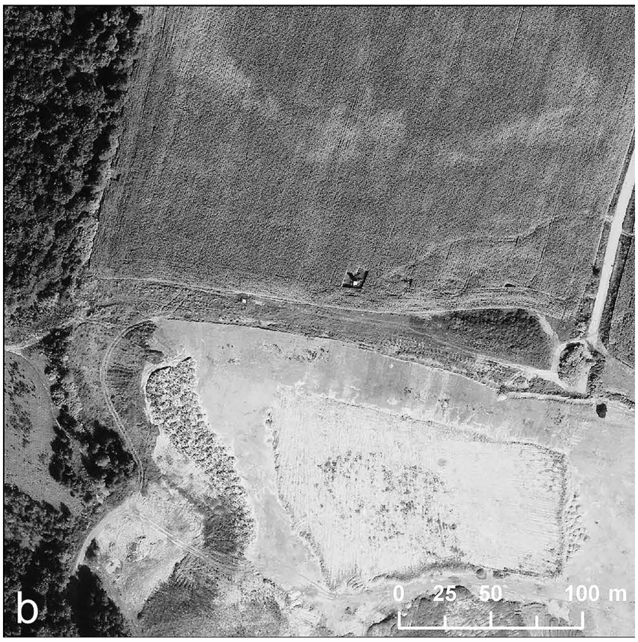


Fig. 14 (a, b) The process of abandonment in the artificial surfaces in Karviná-Doly mining area (a) an aerial photo from 1947 (© MO ČR/GeoSI AČR) and (b) an aerial photo from 2003 (© GEODIS BRNO, spol. s r. o.)

Fig. 15 Contemporary view of the Church of St. Peter of Alcantara in Karviná-Doly mining area. Photo: R. Popelková, 2007

Fig. 16 Church of St. Peter of Alcantara in Karviná-Doly mining area and its vicinity in an orthophoto from 2003 (© GEODIS BRNO, spol. s r. o.)

Fig. 17 (a, b) The area before (year 1947) (© MO ČR/GeoSI AČR) and after (year 2003) the occurrence of a submerged ground subsidence in Lazy mining area (© GEODIS BRNO, spol. s r. o.)

5. Conclusion

Aerial photo-based analysis of the effects of mining on landscape showed that both direct and indirect signs must be taken into consideration in visual photointerpretation (Figure 19). In order to identify the primary and secondary displays of mining activities, stress is put on direct signs contained in a respective photo: shape, size, tone, colour, texture and structure of an object. However, these signs must be complemented with the interpretation of indirect signs, i.e. logical signs that require deep knowledge on the research phenomena (Ciolkosz, Miszalski, Oledzki 1999). Indirect signs used in the interpretation of anthropogenic landforms include particularly the location of an object and its relations to other objects in a photo.

Unlike the primary and secondary mining displays, the processes are absent in the photos, however, they can be derived from multitemporal analysis of aerial photos. Such processes are presumed on the basis of indirect signs in combination with supporting information used in order to differentiate between mining-related processes and other processes that take place in the landscape.

The photointerpretation key of the anthropogenic landforms in the mining landscape was created by the authors for the purpose of detecting landscape changes based on visual photointerpretation of aerial photos. Although it has not been published yet, it has been applied in previously published studies (Mulková, Popelka, Popelková 2010; Mulková, Popelková 2011; Popelková, Mulková 2011; Mulková, Popelková, Popelka 2012; Popelka, Popelková, Mulková 2013).

Correct interpretation of deep mining displays depends on the interpreter's direct experience with activities taking place in the mining landscape. Subsequently, accurate visual interpretation of deep mining displays enables us to quantify the extent of changes, determine their direction and analyse processes in landscape heavily affected by man. Aerial photos represent an important source of information in the study of territorial differentiation of changes, their intensity, character and causes. Complex understanding of these processes makes it possible to analyse historical development of the landscape, predict the landscape evolution and assess ecological and social effects of deep hard coal mining.

Acknowledgements

This research was supported by a grant project of the Grant Agency of the Czech Republic No. P410/12/0487: 'The process of industrialization and landscape changes in the Ostrava Industrial Zone in the 19th and 20th centuries'.

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RÉSUMÉ

Projevy hlubinné těžby černého uhlí na leteckých snímcích

Letecké snímky jsou významným zdrojem dat pro sledování změn v krajině. Hlubinná těžba černého uhlí se v krajině projevuje specifickým způsobem. Pro detekci projevů hlubinné těžby v krajině autorky použily kontaktní kopie archivních černobílých leteckých snímků z období 1947 až 1995 a barevné ortofoto z roku 2003 a 2009.

Projevy hlubinné těžby černého uhlí, které je možné interpretovat z leteckých snímků, autorky rozdělily podle jejich typu do dvou základních skupin: primární projevy hlubinné těžby a sekundární projevy hlubinné těžby. Primárně se hlubinná těžba černého uhlí na leteckých snímcích projevuje výskytem antropogenních tvarů reliéfu přímo spojených s hornickou činností. Patří sem montánní tvary reliéfu (odvaly, poklesové kotliny) a industriální tvary reliéfu (kalové nádrže, manipulační plochy). Oblasti s podpovrchovou těžbou lze identifikovat rovněž na základě přítomnosti povrchových staveb hlubinného dolu. Sekundárními projevy hlubinné těžby na leteckých snímcích jsou antropogenní tvary reliéfu, které nepřímo souvisí s těžební činností. Jedná se o rekultivační plochy, suché kalové nádrže, komunikační tvary reliéfu, povrchy bez vegetace.

Pro správnou interpretaci projevů hlubinné těžby v krajině je nezbytná znalost jejich zobrazení na leteckých snímcích. Pro každou kategorii autorky uvádí podrobný popis a ukázku konkrétního projevu hlubinné těžby na leteckém snímku. Při zjišťování primárních a sekundárních projevů hornické činnosti na leteckých snímcích převažuje práce s přímými znaky, které jsou přímo ve snímku obsaženy: tvar, velikost, tón nebo barva, textura a struktura objektu. Tyto znaky je však potřeba doplnit o interpretaci znaků nepřímých, tj. znaků logických vyžadujících vysokou znalost zkoumaných jevů. Z nepřímých znaků se pro interpretaci antropogenních forem reliéfu využívá zejména poloha a vazby s ostatními objekty na snímku.

Procesy nejsou na rozdíl od primárních a sekundárních projevů hornické činnosti přímo ve snímku obsaženy, ale lze je odvodit z multitemporální analýzy leteckých snímků. Na základě změn krajinného pokryvu je možné interpretovat procesy související s hlubinnou těžbou. Autorky ve studii popsaly a demonstrovaly na příkladech tyto základní procesy: zavodňování a opuštění, které může následně vést k procesu zalesnění. Procesy můžeme detekovat na základě znaků nepřímých s využitím podpůrných informací pro odlišení procesů souvisejících s těžbou od ostatních procesů v krajině.

Fig. 18 Waste bank characterised by self-sustaining combustion in Heřmanice mining area (© GEODIS BRNO, spol. s r. o., 2009)

Fig. 20 Submersion in the Lazy mining area (© MO ČR/GeoSI AČR, © GEODIS BRNO, spol. s r. o., 2003)

Fig. 19 Anthropogenic landforms on aerial photo of Lazy mining area (© GEODIS BRNO, spol. s r. o., 2003)

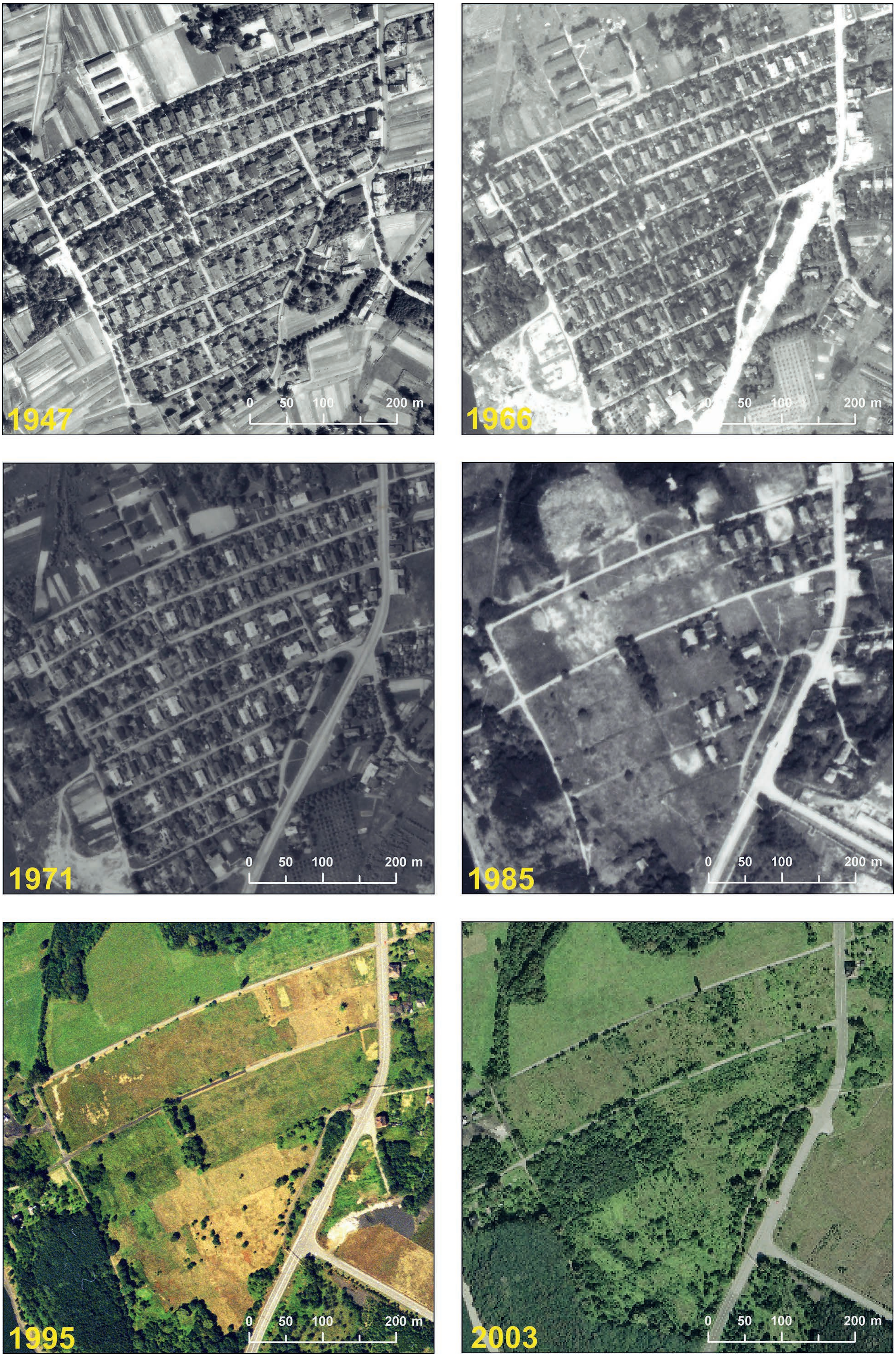

Fig. 21 Abandonment in the area of Chobotova colony in Lazy mining area (© MO ČR/GeoSI AČR, © ARGUS GEO SYSTEM 1995, © GEODIS BRNO, spol. s r. o., 2003)

Fig. 22 Tailings pond (Lazy mining area). Photo: M. Mulková, 2007

Fig. 23 Mine buildings of Lazy mine. Photo: M. Mulková, 2003

Fig. 24 Ground subsidence (Lazy mining area). Photo: M. Mulková, 1998

Fig. 25 Communication landforms (Lazy mining area). Photo: M. Mulková, 1998