

ORIGINAL ARTICLE

Unearthing the shadows of history: Chemical traces of Second World War atrocities in the Szpęgawski Forest and Death Valley, Poland

Dawid Kobiałka¹  | Monika Fabiańska²  | Joanna Rennwanz³  | Iwona Hildebrandt-Radke⁴ 

¹Institute of Archaeology, University of Lodz, Lodz, Poland

²Faculty of Natural Sciences, University of Silesia, Katowice, Poland

³Institute of Archaeology and Ethnology, Polish Academy of Sciences, Poznan, Poland

⁴Institute of Geocology and Geoinformation, Adam Mickiewicz University, Poznan, Poland

Correspondence

Dawid Kobiałka, Institute of Archaeology, University of Lodz, Gabriela, Narutowicza, 65 Street, 90-131, Lodz, Poland.

Email: dawid.kobialka@filhist.uni.lodz.pl

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Abstract

This article presents the results of analyses of the chemical composition of organic matter and the occurrence of characteristic geochemical and biochemical markers in 17 samples collected from the Second World War mass graves excavated in the Szpęgawski Forest and Death Valley, Poland. The results show that attempts to cover up mass crimes by burning the bodies of the victims have left their own traces—that each attempt to cover up the crime is associated with the creation of further evidence of the crimes committed.

KEYWORDS

Aktion 1005, biomarkers, geomarkers, Germany, mass grave, mass killing, Poland, Second World War

INTRODUCTION

Forensic archaeology has become an important branch of archaeological research over the last decades (Anstett & Dreyfus, 2015; Ferrándiz & Robben, 2015; Moran & Gold, 2019). Archaeological research methods and tools are often used to find, document and interpret material traces of crimes—those from several days, weeks and even decades ago. The above observation applies to European (Sturdy Colls, 2015), world (Groen et al., 2015), and Polish (e.g., Kola, 2000, 2005; Ławrynowicz & Żelazko, 2015) archaeology.

In the case of Poland, the concept of forensic archaeology has only recently been used to describe a set of activities aimed at uncovering evidence of crimes committed (Godzień, 2017; Trzciniński, 2013). However, the history of this type of work is long as Poland as a country experienced and was the arena of the darkest pages related to the history of the Second World War

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(Jastrzębski, 1974; Madajczyk, 1970). Concentration camps, death camps and mass graves are only some of the categories of sites that can undoubtedly be classified as crime scenes in the research field of forensic archaeology (Karski & Kobińska, 2021; Sturdy Colls, 2015). It should be noted, however, that this type of research topic is still the domain of historical research—(forensic) archaeology is usually reduced to a research method (a method of finding traces of committed crimes) (e.g., Kola, 2005). However, this has not been the case with the archaeological research in the Szpegawski Forest and Chojnice's Death Valley (Buchholz, 1947; Kobińska, 2022; Kobińska et al., 2024; Lorbiecki, 2017) (Figure 1).

The Szpegawski Forest near Starogard Gdański, Poland, is the site of mass crimes. Between September 1939 and January 1940, the Nazi Germans murdered between 2413 and 7000 people, according to rough estimates (e.g. Kobińska et al., 2024; Kubicki, 2019; Milewski, 1989). Among the victims were the mentally ill, representatives of the local intelligentsia, and Poles who, in one way or another, had accessed the local Germans' black books. In the late autumn of 1944, the mass graves were dug up, the corpses were removed and then burned to erase the traces of the crime. That method turned out to be so effective from the Nazi Germans' perspective that in the final stage of the Second World War in Gdańsk Pomerania, in several cases, they murdered and immediately burned larger groups of people who had not been released (e.g., Wróblewski, 2020). An example of this is the mass crime that took place in the second half of January 1945, when a group of several hundred Poles were murdered near Chojnice, and their bodies were immediately burned to prevent the identification of the victims and their number (e.g. Buchholz, 1947; Kobińska, 2022, 2023).

The aim of the research was (i) to investigate the chemical traces left in the material found in mass graves excavated in the Szpegawski Forest and Death Valley, and (ii) to propose biochemical and geochemical markers that could be applied to document the procedure applied to cover up the crime and its conditions.



FIGURE 1 Sites described in the article: (A–C) contemporary commemoration in the Szpegawski Forest; (B–D) contemporary commemoration in Death Valley in Chojnice (courtesy of D. Frymark).

HISTORICAL CONTEXT

In the context of our argument, it is important to note that field research within the theoretical and methodological framework of forensic archaeology has not been conducted so far in the case of the first and crucial stage of the Second World War (but see Kobiałka, 2022; Kobiałka et al., 2021, 2024). The war began, as is generally accepted, on 1 September 1939, when German troops illegally invaded Poland. One of the key terrains of the attack, and indeed the argument for Hitler's taking military action, was the issue of Gdańsk Pomerania, referred to in German propaganda as the Pomeranian Corridor (in German, *Polnischer Korridor*). The first months of German occupation were also of an exceptional nature in Gdańsk Pomerania, the most tragic manifestation of which were mass crimes committed against the civilian population—the local intelligentsia, but also the mentally ill and members of the small Pomeranian Jewish community (e.g., Bojarska, 1972, 2009; Ceran et al., 2018; Evans, 2004; Jastrzębski, 1974; Wardzyńska, 2009). The victims also included farmers, workers and uneducated people who, in one way or another, had accessed the local Germans' black books in the period preceding the outbreak of the war.

Historians now estimate that between September 1939 and January 1940 the Germans murdered at least 30,000–35,000 Poles at some 400 execution sites in Gdańsk Pomerania alone. This number was twice as high as the rest of the total number of people who lost their lives in the areas that formed the borders of the pre-war Second Polish Republic (Ceran et al., 2018). In the literature on the subject, these events are known as the *Intelligenzaktion* (Wardzyńska, 2009) and T-4 (Evans, 2004). However, Polish historians have recently advocated the use of the term Pomeranian Crime of 1939 as a concept that more fully reflects the nature, scale, territorial and time scope of the crimes committed (Ceran et al., 2018; Kobiałka et al., 2024).

Nazi German war crimes and crimes against humanity from the autumn of 1939 were investigated by Polish law enforcement agencies in the post-war period. They were also of interest to scientists and amateur historians who collected eyewitness accounts after 1945 (e.g., Lorbiecki, 2017; Milewski, 1989). Law enforcement agencies and special commissions carried out exhumations to find the bodies of the murdered people (e.g., Buchholz, 1947; Kubicki, 2019). However, it is worth remembering that these searches were not archaeological studies.

The Pomeranian Crime of 1939 should not be understood as an event on a timeline—as the murder of certain categories of Poles. The process of extermination continued until January 1940 in connection with the murder of residents of the local hospital for the mentally ill. It is rather a process, an integral part of which were the events of the second half of 1944. At that time, Action 1005 (in German, *Aktion 1005*) was carried out in Gdańsk Pomerania, which consisted in the *mass* covering up of mass crimes committed in the autumn of 1939, including those committed in the Piaśnica Forest, the Szpęgawski Forest and Mniszek-Grupa (Hoffman, 2013; Kubicki, 2019). In the autumn of 1944, special commandos were sent to find execution sites, locate mass graves, remove decomposing bodies and burn them in order to erase traces of the crime. These actions were so effective that the actual scale of the crime and the personalities of the people murdered at the given execution sites have not been determined more precisely, either after the war or today (Ceran et al., 2018).

In fact, it was only starting from 2020 that the first archaeological work on the material evidence and social memory of Nazi German crimes from the first months of the Second World War in Gdańsk Pomerania has been carried out (e.g., Kobiałka, 2022, 2023; Kobiałka et al., 2021, 2024). Their methodological framework has been forensic archaeology and the thesis that the use of archaeological research methods and tools, the integration of their results with historical, ethnographic, ballistic, geochemical and other research can shed new light on 'old' crimes of the Second World War.

One of the sites studied as part of the 'Archaeology of the Pomeranian Crime of 1939' project is the Szpegawski Forest (e.g., Kubicki, 2019; Milewski, 1989). The archaeological works were carried out in 2023 on the basis of various archaeological research methods (Kobiałka et al., 2024). During the excavations, approximately 1400 kg of burned human remains and a small amount of unburned bones were recovered. Sampling of wood, soil, charcoal, slag and slaked lime for specialist analysis was part of the fieldwork (Figure 2).

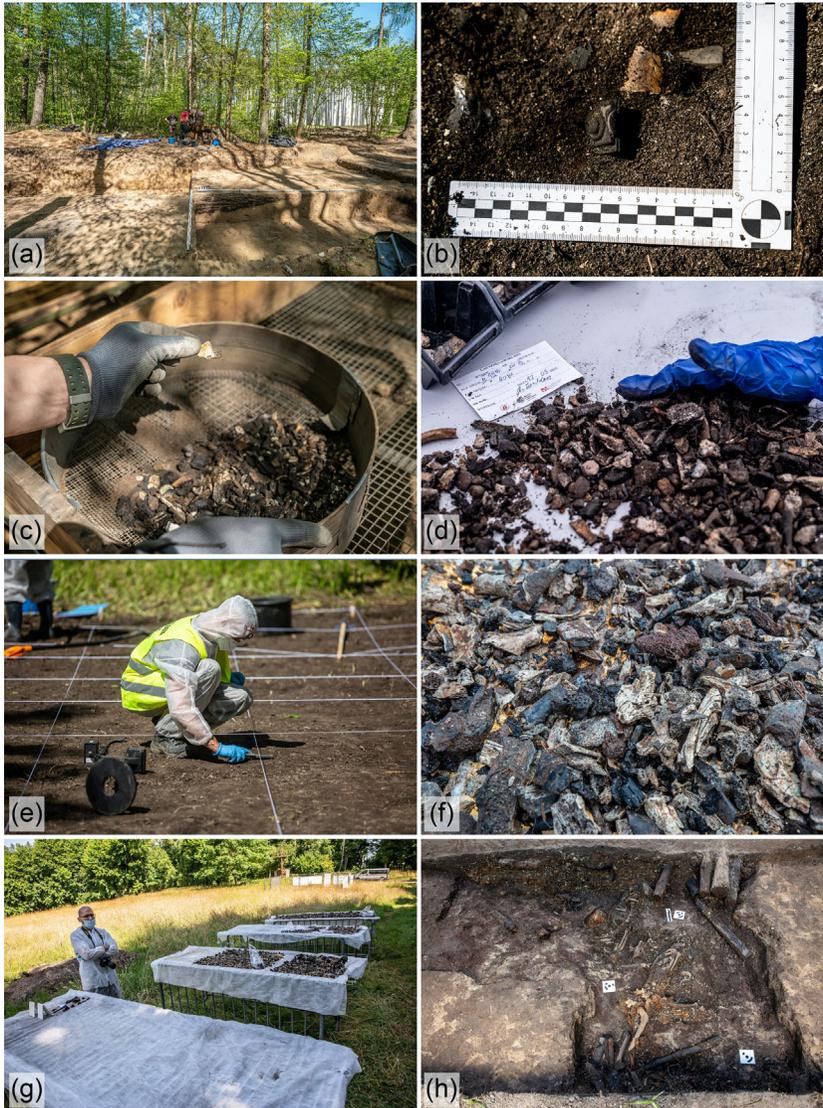


FIGURE 2 Archaeological excavations in the Szpegawski Forest (A–D) and Death Valley (E–H). (A) burial pit during exploration. The black layer visible in the photo consists of burned human remains, among which there are artefacts, wood, charcoal and fragments of slag. (B) A close-up of the evidence of the crime: human bones, an artefact, a fragment of wood. (C) The entire grave fill was sifted during the research. (D) Burned human remains along with fragments of wood and charcoal from the burned layer of the grave. (E) Burial pit during exploration. (F) A close-up of the evidence of the crime consisting of human bones, artefacts, fragments of wood and charcoal. (G) The entire grave fill was floated during the research. (H) Unburned human remains along with fragments of wood from the bottom layer of one of the graves (courtesy of D. Frymark).

Evaluating the environmental conditions of the mass graves' location in the Szpegawski Forest, it should be noted that the site was chosen as a burial site for the 1938 deforested fragment of crevasse fillings built of sandy sediments, elevated slightly above the surrounding terrain depressions. The subsoil of the site contains rusty soils. The mass graves at Szpegawsk therefore occur in dry, permeable soil with an acidic pH.

The second place which was the subject of analyses, showing material evidence of the crimes committed during the Second World War, is the so-called Death Valley near Chojnice (e.g., Kobiałka, 2022; Kobiałka et al., 2021). As in the case of the Szpegawski Forest, in the autumn of 1939 the Nazi Germans murdered several hundred Polish citizens near the town: at least 218 mentally ill people from the local National Social Welfare Institutions, 15 representatives of the local Jewish community, representatives of the intelligentsia (e.g., government officials, clergymen, landowners, members of various types of patriotic organizations) and broadly defined enemies of Germanism. In 2023, a Polish military trench was found, which served as a mass grave for these people. Nevertheless, Death Valley is a unique example of an extermination site associated with the Pomeranian Crime of 1939. According to the current state of research, the Germans did not destroy the graves in the autumn of 1944 as part of *Aktion 1005*. However, mass cremation graves were found in Death Valley. They were evidence of a crime that took place near the town at the end of January 1945, when a group of several hundred people went to Chojnice and never left it. Based on the sounds of gunshots, the stench of burning flesh and the glow of light rising from Death Valley for three days and three nights, the local community assumed that these people had been murdered and their bodies were then burned (Buchholz, 1947). This site was found in 2020, and a year later, nearly a ton of burned human remains and several thousand artefacts were recovered from three burial pits, and almost 300 samples of wood, charcoal and other organic materials were collected for specialized analyses.

In terms of environmental conditions, the execution and burning site of those murdered in 1945 in Death Valley is located in the eastern part of a glacial trough, between an erosional glacial outlier and the eastern edge of the trough. The glacial trough is filled with peat and, on the surface, also with sandy deposits, which is associated with the earlier activity of the Struga Jarcewska. This river currently flows through a channel in the western part of the valley. The deposits filling the trough indicate a peat bog, characterizing the wet nature of the location of the mass graves.

This report discusses selected samples taken from the fills of cremated mass graves in the Szpegawski Forest and Chojnice's Death Valley. Our goal was to try to determine the impact of the process of burning human bodies on ecofacts (e.g., wood, charcoal, earth from grave fills) and their chemical composition, which could be evidence of crimes committed and could be used as markers in the search for similar places where crimes were committed and attempts made to cover them up by burning the victims' bodies.

MATERIAL AND METDHOS

17 samples of ecofacts were selected from the set of material samples taken at the sites of Szpegawski Forest and Chojnice's Death Valley to represent the variability of the material investigated. Among them, two represent the benchmark soil sample taken approximately 500 m from the mass graves. The third is an undisturbed soil profile taken at a site free of mass graves from the Szpegawski Forest and Death Valley (Figure 3).

The analysed material consisted of charcoal—the remains of cremation pyres, excavated from mass graves (Rennwanz, 2021, 2023). Specimens characterized by intense multicoloured and cream-coloured discoloration, visible under the microscope at various magnifications on the surface and within the structure, suggested the presence of chemical substances and were selected for further specialist examination. It is likely that the discoloration is a residue of a



FIGURE 3 Evidence of the crime: (A,B) example of material obtained during archaeological research intended for specialized analyses in Szpeęgawski Forest; (C,D) example of material obtained during archaeological research intended for specialized analyses in Death Valley (courtesy of D. Frymark).

flammable substance used to cremate bodies. The use of such liquids by the Nazi Germans during *Aktion 1005* is known from historical sources. According to the literature on mass crimes from the Second World War based on witness statements, bodies in the Szpeęgawski Forest and Death Valley were placed on a cremation pyre and then doused with flammable liquid. Moreover, several abandoned barrels of such substances were discovered at the crime scene after the corpse-burning procedure had been completed. As mentioned by historians (Kubicki, 2019; Milewski, 1989), tar or a solution of turpentine and tar was used as a flammable liquid for burning corpses in the Szpeęgawski Forest, while Bernard Gralikowski stated the use of a mixture of tar with petrol (Kubicki, 2019). The type of substance used was also directly indicated by the result of chemical analysis. Chemical tests, carried out on materials obtained during the post-war exhumations in June 1947 by the Gdańsk University of Technology, showed that turpentine was used to cremate the corpses in the Szpeęgawski Forest (Kubicki, 2019).

The use of flammable substances to burn bodies of the victims in Death Valley is known from the 1945 testimony of witness Jan Grunt, who recollected that empty barrels were left at the execution site (Kobiałka, 2022). As the flammable substance may still be present in the structure of the charcoal, the fragments that bore traces of discoloration were selected from the set of materials investigated in the project and allocated for further analysis. Furthermore, it is assumed that the charcoal may also contain chemical traces from the massive and intensive burning of bodies. The burial pits from which the material for research was obtained were mass graves of the remains of several hundred people.

Sample preparation

Samples S1–S3, S6, S7 and S17 were powdered in a planetary ball mill (Retsch, PM 100), and samples S4, S8–S11 and S12–S16, due to their low weight, were manually ground in an agate

mortar to an analytical grain size of 0.2 mm. Weighted samples were macerated in dichloromethane (DCM) for 3 h and ultrasonicated (3×15 min). The extracts were combined, and the solvent was evaporated at ambient temperature. Extraction yields ranged from 0.003% to 0.725% w/w (dry extract:sample) (Table 1). The extracts were dissolved in DCM and transferred quantitatively to vials of 2 mL capacity with glass inserts (0.2 mL), and were sent for chemical composition analysis by gas chromatography–mass spectrometry.

Gas chromatography–mass spectrometry

Because of the low yields, the extracts were not group fractionated but analysed as totals. Their composition was investigated using an Agilent 6890 gas chromatograph coupled with an Agilent Technology 5973 mass spectrometer and equipped with an automatic injection system. A DB-35 column was applied (60 m \times 0.25 mm id, 0.25 μ m stationary phase film) with He (purity 99.9999%) as a carrier gas. Injection volume was 1.5 μ L, split/splitless mode. The temperature program was as follows initial temperature 50°C (isothermal for 2 min); heating rate, to 175°C at 10°C/min, to 225°C at 6°C/min and, finally, to 300°C at 4°C/min. The final temperature was held for 20 min. The mass spectrometer operated in electron ionization mode (70 eV) in full-scan mode and scanned in the mass range m/z 50–650 a.u. The compounds were identified by mass spectra, comparison of peak retention times with those of standards, and literature data (Philp, 1985; *The Wiley/NBS registry of mass spectral data*, 2012). All solvents and reagents were of analytical reagent grade (Avantor Performance Materials Poland SA). The purity of all solvents and the standard applied were checked under the same analytical conditions as those used for extract analyses. Peaks were integrated manually. The quantitative analysis was done based on the 10-point calibration curve for *n*-dodecanonitrile (Sigma-Aldrich). The linear correlation between the peak areas and nitrile concentrations was checked within the

TABLE 1 Description of samples, codes used in further analysis and extraction efficiency (courtesy of M. Fabiańska).

Code	Type of sampled material	Site	Extraction yield (%wt)
S1	Slaked lime	Szpegawski Forest	0.004
S2	Charcoals	Szpegawski Forest	0.025
S3	Slag with ashes	Szpegawski Forest	0.003
S4	Charcoals	Szpegawski Forest	0.073
S5	Soil outside the grave	Szpegawski Forest	0.009
S6	Soil outside the grave	Szpegawski Forest	0.005
S7	Soil outside the grave	Szpegawski Forest	0.002
S8	Charcoals	Death Valley	0.725
S9	Charcoals	Death Valley	0.131
S10	Charcoals	Death Valley	0.108
S11	Charcoals	Death Valley	0.128
S12	Wood	Death Valley	0.054
S13	Wood	Death Valley	0.063
S14	Wood and charcoal	Death Valley	0.023
S15	Charcoal	Death Valley	0.056
S16	Charcoal	Death Valley	0.017
S17	Soil outside the grave	Death Valley	0.003

range 0.07–7.00 $\mu\text{g/mL}$, with a coefficient of 0.9888. For quality assurance and quality control, the analysis of each sample series was accompanied by the analysis of a blank sample in order to assess possible contamination during the analytical procedure. The limits of detection (LODs) were calculated as three times the standard deviation of background peaks in the procedural blanks. LOD values were 3.5 ± 0.05 ng/mL.

RESULTS

General composition of extracts

Extract yields are highly variable and range from 0.002 (S7) to 0.725% (S8) (by weight). The lowest extract yields were for the benchmark and soil profile samples, on average 0.005% (by weight), whereas charcoal samples mostly showed extract yields 10–100 times higher. Low extractability was also found for sample S3, composed of ashes. Extracts are composed of a mixture of organic compounds comprising *n*-alkanes ($m/z = 71$) (samples S1–S17), polycyclic aromatic hydrocarbons (PAHs) in the range from two to five rings in a molecule ($m/z = 128, 178, 202, 228, 252, 276$), where samples S2, S5–S7, S10, S12, S14–S15 and S17 samples contained the whole range, and S4, S8–S9, S11, S13 and S16 samples contained only two- to three-ring PAHs, saturated fatty acids ($m/z = 73$) (S2, S3, S5–S7, S8, S10, S11, S14–S17), methyl esters of fatty acids ($m/z = 74$) (S3, S5, S8, S10, S11), long-chain aliphatic nitriles (S1, S2, S4, S9–S11, S13–S15) ($m/z = 97$) and amides (S3[?], S4, S10, S12–S15) ($m/z = 72$).

Organic compound distribution

n-Alkanes

Sample S1 (lime) shows a pyrolytic, Gaussian profile of *n*-alkanes ($n\text{-C}_{16}$ to $n\text{-C}_{32}$), typical of oxygen-deficient thermal decomposition of organic matter. Due to the absence of *in situ* organics in this sample, these compounds come only from burning material and entered the lime as a result of evaporation and condensation on the particles. Based on the boiling points of the compounds present, it can be estimated that the combustion temperatures were in the range of 390–430°C (but not higher than 450°C due to the lack of heavier *n*-alkane homologues). Samples S13 (wood), S4 and S10 (charcoal) had a similar *n*-alkane profile to S1 (lime).

The highest concentrations of *n*-alkanes were found in sample S2 (charcoal), where the bimodal distribution (maximum for $n\text{-C}_{15}$ and $n\text{-C}_{26}$) included compounds in the $n\text{-C}_{14}$ to $n\text{-C}_{31}$ range. Heavier compounds had a Gaussian profile similar to that found in sample S1. The lighter *n*-alkanes most likely derive from the thermal decomposition of wood. Lighter *n*-alkanes also appeared in the S8, S9, S11 and S15 charcoal samples, where the probable combustion temperatures were lower and oscillated around 320–360°C.

Sample S3 (slag) is the only one in the population that shows an *n*-alkane profile enriched in compounds originating from the soil—that is, long-chain *n*-alkanes with an odd number of carbon atoms in the molecule, typical of vascular plant material. The remaining part of the *n*-alkane distribution is similar to sample S2 (charcoal)—that is, rich in light compounds.

Fatty acids and their derivatives

In samples S2–S17, fatty acids ranging from hexanoic (caproic) acid (C_6) to stearic acid (C_{18}) were found, with a predominance of compounds with an even number of carbon atoms in the

molecule—a feature deriving the source biological material. In all samples, the distribution is dominated by saturated fatty acids, with palmitic acid (C_{16}) present in the highest concentration, followed by stearic acid (C_{18}) and myristic acid (C_{14}). Unsaturated fatty acids, including oleic acid (C_{18}) and palmitoleic acid (C_{16}), occur in low concentrations, perhaps due to the saturation of their double bonds or—due to higher reactivity—transformation to amides and nitriles during combustion. However, there is a significant difference between samples related to mass graves and the benchmark (S17) (soil) and profile samples (S5–S7) (soil). The latter does not contain lighter fatty acids—that is, from C_6 to C_{10} acids or only in trace amounts. Their distribution is dominated by even-carbon-number long-chain fatty acids and their methyl esters commonly found in soils. Whereas short-chain fatty acids can be found in plant material (Berrie et al., 1976), in this case they probably originate from longer-chain compounds as their decay products.

The distribution dominated by palmitic and stearic acids is typically found in animal fats and indicates the origin from burned bodies. In the case of the charcoal samples (S2, S4, S12–S15), this group of compounds did not contain any originating from modern plant material that was not subjected to high temperatures. Methyl esters of fatty acids show a similar distribution to their corresponding acids.

Aliphatic nitriles and amides

A diagnostically important group of components in the investigated material are aliphatic long-chain nitrile derivatives. In the literature, their presence is associated with the processes of incomplete combustion of biomass, in particular tissues of animal origin, under open-fire conditions (Lejay et al., 2016). The formation would be based on the reaction of ammonia from thermally degraded proteins with fatty acids from the thermal degradation of triglycerides (Vanoye et al., 2019). The reaction would lead to the formation of amides, which would then be dehydrated to nitriles under pyrolytic conditions (Simoneit et al., 2003; Wang et al., 2017) (Figure 4). They have been proposed as biomarkers of frying/grilling in atmospheric aerosols (Simoneit et al., 2003). From archaeological contexts, aliphatic amides and nitriles have been described as well, for example by Wang et al. (2017) (samples 4000–5050 years old) and Collins et al. (2017) (~60,000 years), while demonstrating their significant resistance to degradation. Simulation studies by Jambrina-Enriquez et al. (2019), compared with actual samples from Neanderthal sites, indicate the potential of these compounds as markers of the maximum pyrolysis temperature because they are formed in the range of 250–350°C and disappear at temperatures above 450°C. At the same time, the presence of fatty acids in the reaction medium was demonstrated as a necessary condition for their synthesis.

Aliphatic nitriles were found in significant amounts in eight samples from the 14 samples related to mass graves: samples S2, S4, S7, S10, S11, S12, S14 and S15; however, they were also present in S1, S9 and S13 samples although in low concentrations (Table 2). The soil profile samples (S6, S7) were devoid of them, as well as the S16 sample (charcoal). The benchmark sample (S17) contained only one nitrile: laurionitrile (C_{12}). As it is the lightest of this group of compounds, it is possible that the distance of 0.5 km from the mass graves was not sufficient and that this compound was released into the environment with the fly ash.

Laurionitrile (C_{12}), tridecanonitrile (C_{13}), myristonitrile (C_{14}), pentadecanonitrile (C_{15}), palmitonitrile (C_{16}), octadecanonitrile (C_{18}) and nonadecanonitrile (C_{19}) were identified in the extracts investigated, with the highest concentrations occurring in the S2 sample (charcoal), perhaps due to the sorption properties of this medium (Figure 4B). Other charcoal samples (S4, S12–S15) also contained them; however, their range varied from one or two compounds present—that is, miristonitrile and palmitonitrile as in samples S1 (lime) and S9 (charcoal) samples or palmitonitrile in the S15 (charcoal) sample—to the C_{11} – C_{19} nitriles as in samples S4 and

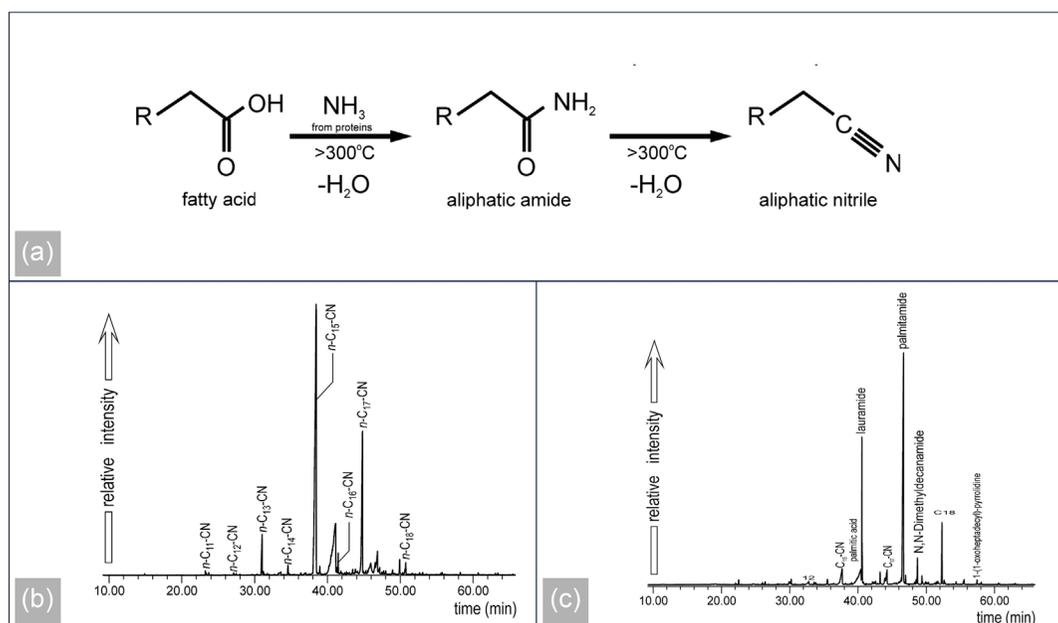


FIGURE 4 Results of the chemical analyses: (A) mechanism of aliphatic amide and nitrile formation via ammoniation–dehydration. Example of gas chromatographic–mass spectrometric distribution of fatty acid thermal derivatives in the material investigated (sample S2); (B) aliphatic nitriles ($m/z = 97$); (C) aliphatic amides ($m/z = 72$) (courtesy of M. Fabiańska).

TABLE 2 Concentrations of aliphatic nitriles in the soil samples [$\mu\text{g/g}$] (courtesy of M. Fabiańska).

Code	<i>n</i> -C12 nitrile	<i>n</i> -C13 nitrile	<i>n</i> -C14 nitrile	<i>n</i> -C15 nitrile	<i>n</i> -C16 nitrile	<i>n</i> -C17 nitrile	<i>n</i> -C18 nitrile	<i>n</i> -C20 nitrile	Sum ^a
S1	<0.0035	<0.0035	0.0247	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	0.0247
S2	0.0716	0.0473	1.0811	0.1803	15.0112	0.3278	5.0627	0.0362	21.8183
S3	<0.0035	<0.0035	0.0037	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	0.0037
S4	0.0556	0.0319	0.1662	0.0378	0.8476	0.0341	0.2337	<0.0035	1.4068
S5	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035
S6	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035
S7	0.0092	<0.0035	<0.0035	<0.0035	<0.0035	0.0050	0.0036	<0.0035	0.0178
S8	<0.0035	<0.0035	<0.0035	<0.0035	0.2381	0.3761	0.2116	<0.0035	0.8259
S9	<0.0035	<0.0035	<0.0035	<0.0035	0.0716	0.1091	0.0390	<0.0035	0.2197
S10	0.1110	0.0161	0.2030	0.1019	0.9937	0.0495	0.3567	0.0193	1.8513
S11	<0.0035	<0.0035	<0.0035	0.8642	0.1443	0.0933	0.0620	<0.0035	1.1638
S12	0.0220	<0.0035	0.0520	0.0077	0.0210	216.7849	<0.0035	<0.0035	216.8875
S13	0.0384	<0.0035	<0.0035	0.1289	0.0268	0.0631	<0.0035	<0.0035	0.2572
S14	0.0234	0.0146	0.0781	0.0315	0.1718	<0.0035	0.0861	<0.0035	0.4055
S15	0.1215	0.0298	0.1164	0.0207	0.0316	0.0316	<0.0035	<0.0035	0.3516
S16	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035
S17	0.0126	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	<0.0035	0.0126

^aTo calculate a sum of nitriles, only values above LOD were taken.

S12–S15. The distribution showed a predominance of compounds with an even number of carbon atoms in the molecule, with the maximum for palmitonitrile. This feature indicates saturated fatty acids as substrates for nitrile formation (Figure 4), showing an analogous distribution in the samples as described above.

Nitrile derivatives were accompanied by aliphatic amides, present in lower concentrations, which are intermediate products of the nitrilation reaction. Lauramide (C_{14}), palmitamide (C_{16}), oleamide ($C_{18:1}$) and stearamide (C_{18}) were identified in samples S2, S10, S11, S4 and S12–S15 (wood and charcoal), with the highest concentrations again occurring in sample S2 (charcoal) (Figure 4).

Based on the above data, it can be assessed that the temperatures to which the material investigated was subjected were in the range of 250–450°C. Quantitatively, nitriles were important components of S2, S10, S11, and S4, S12–S15 extracts, and their contents calculated on the basis of the peak areas of the total ion chromatogram ranged from a few percent (S4, S10–S15) to as much as 31.6% (sample S2).

In further research, the presence of amides and aliphatic nitriles in the earth of this area can be treated as an indicator of the presence of burned human remains, in particular when their absence in the benchmark soil (S17) and soil profile samples (S5–S7) are taken into account.

Polycyclic aromatic hydrocarbons (PAHs)

The sample extracts are surprisingly low in PAHs. No naphthalene, acenaphthylene or acenaphthene was detected. The lightest PAHs were phenanthrene and anthracene ($m/z = 178$), followed by pyrene and fluoranthene ($m/z = 202$), benzo(ghi)fluorene, benzo(a)anthracene and chrysene ($m/z = 228$), benzofluoranthenes, benzo(a)pyrene, benzo(e)pyrene and perylene ($m/z = 252$), indeno[cd-1,2,3]pyrene and benzo(ghi)perylene ($m/z = 276$). The complete PAHs range was found in the charcoal samples, benchmark and soil profile. Samples S1 (lime) and S3 (slag) contained only pyrene and fluoranthene; sample S11 (charcoal) contained only phenanthrene and anthracene; and samples S4, S8 and S9 (charcoal) contained phenanthrene, anthracene, pyrene and fluoranthene. It can be assumed that PAHs in charcoal samples were formed in situ from wood smouldering in oxygen-deficient conditions. At the same time, they were transferred to the remaining samples during the burning of bodies as a result of evaporation. This is confirmed by the presence of retene in the extracts, a typical component of tar and products of incomplete combustion of wood and terrigenous fossil fuels. However, PAHs are natural products of organic matter aromatization (Peters et al., 2005), occurring even at low temperatures or possibly transported from elsewhere with atmospheric dust for distances exceeding a few tens of kilometres (Bi et al., 2008; Tang et al., 2005). Soil and sediments, due to their sorptive properties, are the sites of PAHs immobilization and accumulation, where these compounds can be stored for many years (e.g., Charriau et al., 2009). This explains their presence both in the benchmark and soil profile samples.

DISCUSSION

Geochemical and biochemical markers of fuel

No diagnostic compounds (biomarkers) derived from fossil fuels, such as pentacyclic triterpanes (hopanes and moretanes) ($m/z = 191$) or steranes ($m/z = 217$), were detected in the extracts (Peters et al., 2005). These compounds occur commonly in sedimentary organic matter and are characterized by significant resistance to biodegradation, low-temperature oxidation and combustion processes (Bi et al., 2008; Fabiańska et al., 2017). There are examples described in the

literature of the survival of these substances in various types of soils and sediments, even for several dozen years (e.g., Charriau et al., 2009; Fabiańska et al., 2016; Yunker et al., 2002). Due to their high molecular weights (above 300 a.u.), they are of low volatility; hence they are associated either with the mineral phase or with the unburned macromolecular fraction of organic matter (e.g., Fabiańska & Smółka-Danielewska, 2012), which results in their relatively high durability. Trace amounts of these substances also occur in light fractions of crude oil, such as gasoline; and after evaporation of the light components, they are concentrated to analytically detectable levels (e.g., Zając et al., 2022). Their absence in the tested material indicates the use of a fuel other than liquid fossil fuels.

Research carried out just after the Second World War in the Szpęgawski Forest suggested technical turpentine as the fuel applied (Kubicki, 2019). Thus, the focus was also on its components—that is, α - and β -pinene, δ^3 -carene, camphene, dipentene and terpinolene ($m/z = 98, 121, 136$) (Kupczewska-Dobecka & Czerczak, 2006). Unfortunately, these substances are highly volatile, so they were not preserved in the material investigated. It should be noted that the extracts are generally low in compounds with low atomic masses (up to 150 a.u.), which may result from evaporation into the air during combustion and washing out with water seeping through highly permeable soil (Hildebrandt-Radke, 2023). The indicator of light-weight fuel application can be the enrichment of the PAH profile in pyrogenic PAHs, among them fluoranthene and pyrene, which are the most prominent in the PAH distribution in the charcoal samples.

The heavier residual components of turpentine, which are part of rosin—that is, pimaric and abietic acids ($m/z = 285$ and 287 , respectively), and which constitute the tail in technical turpentine, were not found.

Aliphatic amides and nitriles as mass grave diagnostic markers

Aliphatic amides and nitriles occurred in variable but still high concentrations in the samples investigated. The sum of nitrile concentrations was in the range from 0.0081 to 216.8875 $\mu\text{g/g}$, with the charcoal samples containing 3.1245 $\mu\text{g/g}$, on average, although sample S12 (wood) had an extremely rich content. These compounds are products of incomplete tissue combustion (Wang et al., 2017); they are saturated compounds, and their distribution correlates with the predominance of saturated fatty acids in the material investigated. Thus, in the context of archaeological research on the Pomeranian Crime of 1939, the presence of high contents of aliphatic amides and nitriles in the soil can be considered an environmental marker of burned human remains. Even when macroscopic traces were not preserved at the particular site, these compounds can confirm the presence of mass graves.

CONCLUSIONS

Nazi German crimes in the Szpęgawski Forest and Death Valley during the Second World War were well organized and executed. Material traces, both the bodies of the victims and what the Poles had with them at the time of death, were additionally burned in order to erase the traces of the crimes committed as thoroughly as possible. These measures were so effective that it is impossible to determine the exact number of victims or their personal details, either immediately after the war or today. Nevertheless, there is no such thing as a perfect crime. Mass crimes generate massive amounts of traces. The mass effacement of mass crimes also involves the creation of further traces. This is in fact the case with the crimes in the Szpęgawski Forest and Death Valley. The analyses carried out extend the spectrum of traces left after the crimes at the level of geochemical markers. Our conclusions can be summarized as follows:

- The distribution of fatty acids and their esters, dominated by saturated compounds, is typical of animal fats and indicates the origin of these compounds from burned bodies. There was no significant contamination of the material by acids found in soils.
- In the context of archaeological research on the Pomeranian Crime of 1939, the presence of high contents of amides and aliphatic nitriles in the earth can be treated as a diagnostic indicator of the presence of burned human remains.
- Pyrolytic, Gaussian profiles of *n*-alkanes with a maximum at *n*-C₂₆ and the presence of aliphatic nitriles indicate combustion temperatures not exceeding 450°C. Thermal conditions were variable, and temperatures oscillated between 320 and 360°C for some samples or in a slightly higher range of 390–430°C.
- No geochemical markers of liquid fossil fuels or turpentine components were found; therefore, the problem of the fuel used to burn the bodies remains unresolved.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

PEER REVIEW

The peer review history for this article is available at <https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/arcm.13013>.

DATA AVAILABILITY STATEMENT

Dear Editors, the data constituting the basis of the submitted text are part of an official investigation conducted by the prosecutor's office of the Institute of National Remembrance in Gdańsk, Poland. They will only be made available after the investigation is completed, which is planned for next year.

ORCID

Dawid Kobiątka  <https://orcid.org/0000-0003-3806-4408>

Monika Fabiańska  <https://orcid.org/0000-0002-8270-9384>

Joanna Renmwanz  <https://orcid.org/0000-0002-1151-0941>

Iwona Hildebrandt-Radke  <https://orcid.org/0000-0001-7028-3235>

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