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TRACE EVIDENCE: A ROLE AND IMPACT ON FORENSIC SCIENCE AND THE CRIMINAL JUSTICE SYSTEM

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Abstract

In criminal investigations, the analysis of DNA and the examination of fingerprints are typically used as credible and reliable evidence for personal identification in courts worldwide. However, DNA samples and latent prints are not always recovered from a crime scene.

Locard's principle states that when two objects come into contact, each will pick up or leave something upon the other. This implies that people who commit crime will always leave something behind. This transferred material is referred to as trace evidence. In comparison to DNA and fingerprints, trace evidence is considered of less value for proving personal identity but can provide strong clues and valuable information to link a criminal to a scene or a victim. Trace evidence also has the ability to tell a story of what actually happened, how it occurred, and who or what may have been involved. It is very helpful in establishing a sequence of events in crimes and providing the linkages or associations that lead to a scene reconstruction.

In recent years, trace evidence has become an essential field for forensic science and plays a crucial role in crime solving. Even when DNA or fingerprints are not present at a crime scene, trace evidence may be left behind. When trace evidence is uncommon or uniquely found at a particular scene it will be of the highest importance and crucial to an investigation. .

This paper reviews and demonstrates the important role of different types of trace evidence in forensic science and its impact on the criminal justice system by examining real forensic caseworks worldwide.

Keywords: Trace Evidence, Locard's principle, Forensic Science, Criminal Investigation

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1. INTRODUCTION

"Trace evidence" refers to physical evidence or material that is usually found in small size (often microscopic) and can be easily transferred or exchanged simply by physical interaction between objects and individuals (Max M. Houck, 2009). It first became an important part of forensic science in the early twentieth century when Dr. Edmond Locard, a French criminologist, formulated his theory that "Every contact leaves a trace". The principle of exchange states that whenever two objects or individuals come into contact, each will pick up or leave something upon the other; a cross-transfer of trace materials takes place. This concept, known as Locard's exchange principle, became fundamental to all forensic work and is important in today's law enforcement (Horswell & Fowler, 2004).

Trace evidence is one of several forensic science disciplines that plays a crucial role in criminal investigation by providing a potential link between suspects/victims or objects to crime scenes, a suspect and the victim, a victim and a scene, or the suspect and a scene (De Forest et al., 1983). It is often used to assist or lead the investigators for initial assessment of crimes. Trace evidence also helps to tell a story and put together pieces of the puzzle to create a clearer picture of what happened. For example, it could give insight into: Which direction a vehicle came from? How close a shooter was to a victim when a shot was fired? Which direction a bullet came from? What type of weapons or vehicles criminals used in a bank robbery? Or how many shots were fired, and which shot was fired first? The answers to these questions can significantly impact the conclusion of an enquiry and these answers can be obtained through a thorough examination of the trace evidence.

Several trace materials commonly found in crime scenes include, but are not limited to, human hairs, animal hairs, fibers and fabrics, glass, paint chips, gunshot residues, explosive residues, soil, tape, ink, bulb filaments, tool-marks, footwear and tire impressions, fire debris and miscellaneous unknown substances (Fig.1). The examination of these materials requires a variety of analytical tools, such as microscopical and instrumental techniques, to locate and examine evidence (Trejos et al., 2020), identify and classify the material composition and construction, determine and compare the source of origin that the materials could have originated from the same source or from another source that shares similar characteristics (Max M. Houck, 2001). For example, the examination of a tire impression recovered from a hit and run case can assist the investigator into narrowing the search of suspect vehicles (Bodziak, 2008). Fibers and hairs recovered from a victim's clothing could be used to link to a suspect and scene (Brown & Erickson, 1978). The finding of gunshot residue deposited on a suspect's hands or clothing could indicate that they may have discharged a firearm (Shaw, 2019). Also, the examination of glass fractures could indicate the direction of the breaking force in a housebreaking, road accidents, and shooting incidents, etc. (Harrison et al., 1985).

Although trace evidence can help to establish a sequence of events and provide linkages or associations that can aid crime-scene reconstruction and intelligence investigations, the value of trace evidence has traditionally been criticized, underestimated,

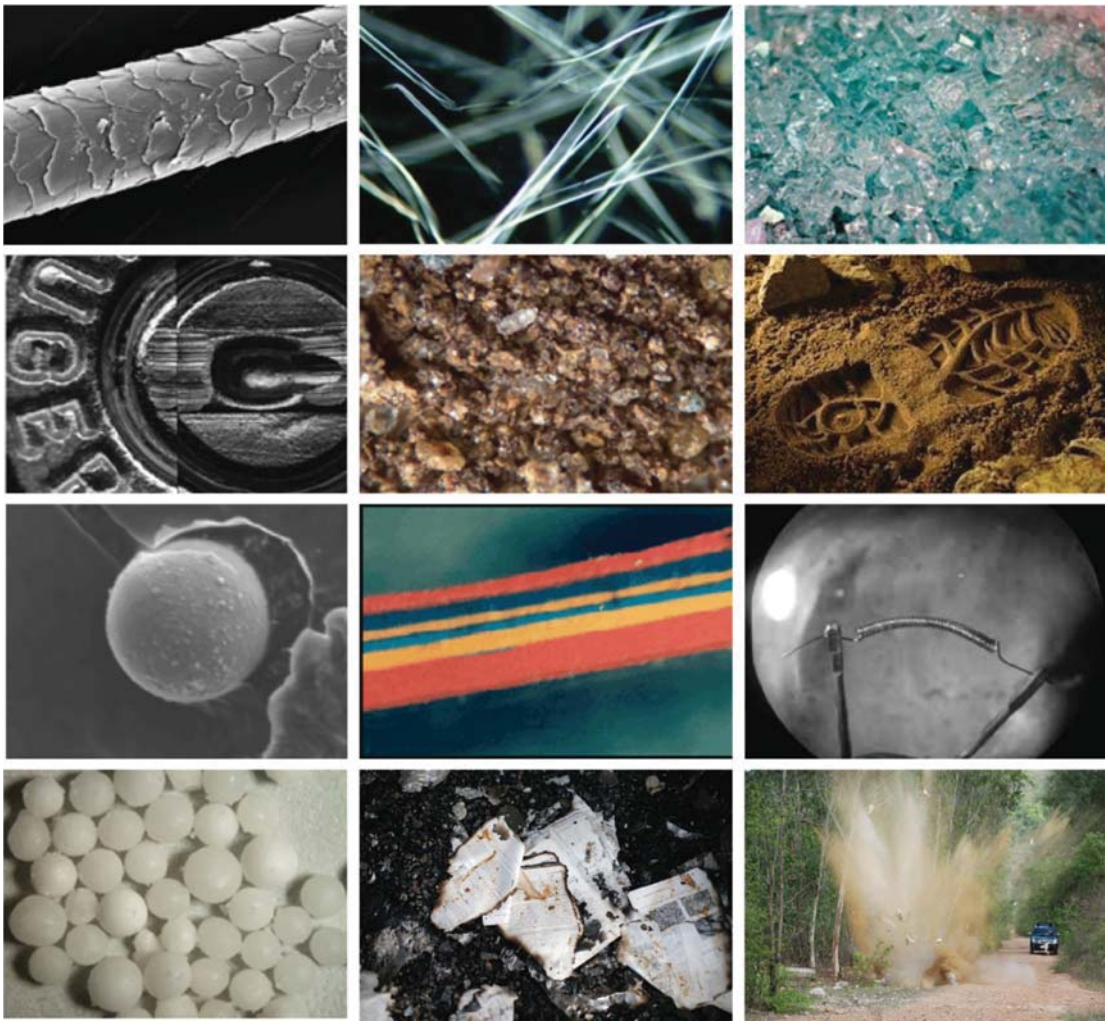


Fig. 1 Types of trace evidence

and underutilized, since its detection and collection are often neglected. This is because small pieces of evidence may not be visible to the naked eye of investigators; they may lack knowledge and understanding of trace evidence; collection of trace evidence is time-consuming and labor-intensive; it is a costly use of resources, and there are challenges in its interpretation (Stoney & Stoney, 2015). In comparison to DNA and fingerprints, trace evidence is considered to have a lesser identifying value where it can only be used to exclude an individual from an investigation but cannot directly link or identify an individual subject or specific object.

In recent years, DNA testing has been required on all biological evidence in cases as it is extremely sensitive and selective for personal identification and a useful tool in leading criminal investigations through the DNA database system (Machado & Granja, 2020). However, DNA or fingerprint analysis are not always evidential or present, and sometimes cannot be successfully recovered from scenes. And even if they are, there may not be sufficient evidence to identify the criminal. In a lot of cases, there is undetectable or no biological evidence left at the scene

since criminals often wear gloves and face masks to avoid leaving fingerprints and DNA. In some homicide cases, DNA and fingerprints cannot be recovered because the victim's body was submerged in the water. In addition, a suspect's DNA is rarely found in cases where a victim's body has been burnt. And in the case where a suspect is a family member or acquaintance of the victim, the presence of the suspect's DNA may not necessarily be informative in such cases. In this instance, trace evidence would be requested to take part as non-DNA evidence to help solve crimes (Woodman et al., 2020).

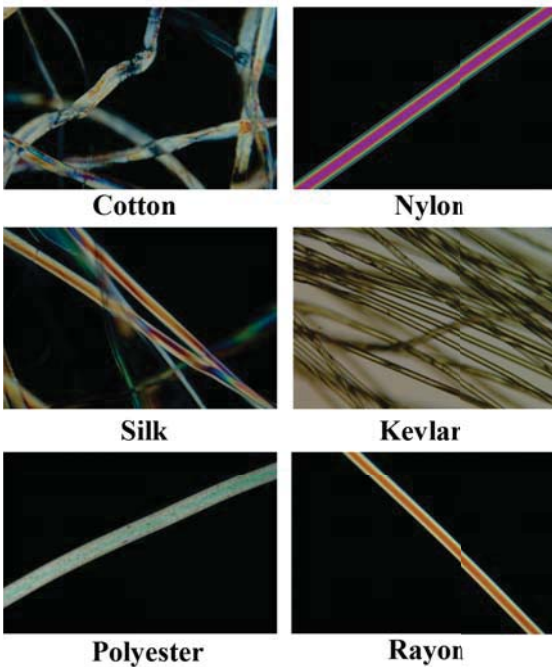
As previously mentioned, trace evidence tends to be only considered in cases where DNA or fingerprint evidences are not readily available, or where it is able to provide sufficient information for investigators. In those certain cases, trace evidence will act as 'supporting evidence' and mainly for court purposes. In order to empower investigators and criminal justice stakeholders to clearly understand the value of non-DNA forensic evidence—*trace evidence*, this paper aims to detail the important role of different types of trace evidence in forensic science and the impact in the criminal justice system by examining real forensic caseworks worldwide. The investigation, trial, and criminal convictions are also reviewed.

2. EXPLORING JUSTICE THROUG A TINY PIECE OF TRACE EVIDENCE

In real life, not all crimes are easy to solve. Careful and smart criminals often leave little to no evidence behind at the scene; making the investigators work difficult and challenging. In cases where DNA or fingerprints are not found, or where they are found but are not in the database system, an accumulation of trace evidence can ultimately assist, support, and lead to a successful trial and conviction. Sometimes, it only takes just one small piece of evidence to catch a criminal. Trace evidence can be used to link objects, individuals, and places. Investigators can potentially find a connection between a suspect and a victim to a mutual location through the corroboration of trace evidence. As described below, a tiny piece of forensic evidence can play a crucial role in crime solving and directly impact the criminal justice system.

2.1 Fiber: a thread to prove a murder

"Fiber is considered the smallest unit of a textile material. It is a fine, thin, and long strand filament or thread-like shape made of a natural or synthetic substance. It is globally used in clothing, household products, and the fashion and retail industries. Fiber is probably the most abundant form of trace evidence found at a scene which can be easily be transferred or exchanged between two or more individuals or objects during a simple contact or interaction (Robertson et al., 2017). *Fibers can be collected at the scene using tweezers, tape, or a vacuum. They generally originate from clothing, furniture, carpets, curtains, bedding, and wigs. The most common technique used for fiber analysis is microscopic examination. Different types of microscopes are used to examine the morphology and physical structure of fibers such as color, shape, and size. For chemical analysis, chromatographic, spectrophotometric and spectroscopic techniques are usually used to analyze dye, additives and compositions of each fiber."* (Nirvani & Campiglia, 2018)



Natural and synthetic fibers under polarized light microscope
Source: *Forensic Chemistry Section, Central Institute of Forensic Science, Thailand*

Case story

During the early morning hours at 3:42 am on February 17, 1970, Dr. Jeffrey MacDonald, a US Army captain, and Green Beret, reported a "stabbing" and called military police to his family's home at Fort Bragg, North Carolina. When the military police arrived, they found the front door closed and locked and the house dark inside. After entering inside from the unlocked back door of the house, they found Dr. MacDonald waring only blue pajama bottoms lying alive but wounded on the bedroom floor next to his pregnant wife who was stabbed and clubbed to death. A matching pajama top found on the chest of his wife. His two daughters were found dead in their own bedrooms with head injuries and multiple stab wounds to their bodies. Dr. Macdonald had suffered cuts and bruises to his face and a single stab wound to his chest. He was taken to a nearby hospital and released after one week.

Dr. Macdonald told investigators that late on the evening of February 16, he was asleep on the couch in the living room when he was awoken by the screaming of his two daughters. He ran to his daughters and was suddenly attacked by three male and one female intruders. He claimed that he was beaten by a club and ice pick. During the flight, his pajama top was pulled over his head and he said he used it to wrest the ice pick from the intruders. He also stated that he was knocked unconscious on the floor near his bedroom (Nickell & Fischer, 1999).

Case Investigation

After searching the house, investigators found a blood-stained club, an ice pick, and a kitchen knife in the backyard. However, investigators had doubts about Dr. Macdonald's story. The investigators saw lack of damage in the living room where Dr. MacDonald claimed he fought with three male intruders. Also, he had no defensive wounds on his arms or hands consistent with a fight, and his wounds were not as severe or numerous as those his wife and daughters had suffered. The investigators believed that Dr. Macdonald's wounds might be self-inflicted as he is a physician. At the scene, blue fibers from MacDonald's pajama were found almost everywhere around and over his two daughters' bedrooms, under his wife's body and even under one of his daughter's fingernails. Yet, none of the blue fibers were found in the living room where he claimed that he was attacked,

and his pajama top was torn and pulled off. Furthermore, blood from one of his daughters was found on the pajama top, even though Dr. MacDonald claimed that his pajama top was ripped off during the fight before he reached to her bedroom.

Case trial and conviction

Nine years after the murders were committed, the trial began on July 16, 1979. Scientific evidence and witness statements related to Dr. MacDonald's case were used to prove to the jury that the defendant committed the murders. The blue fibers showed a link and possibility of interaction between Dr. Macdonald and his wife and daughters. Dr. Macdonald took the stand in his own defense but was unsuccessful in explaining to the jury how his pajama top was found on his wife's chest. He was unable to offer any explanation to counter the forensic trace evidence, or to convince the jury that he had not committed the murders. On August 26, 1979, his conviction resulted in a sentence of three consecutive life terms (Woolverton, 2020).

In this case, DNA test results did not match to any other individuals or known suspects, only the Macdonald family members. This clearly illustrates that DNA is not always the most important information in cases where the suspect is has an intimate relationship with the victim(s) or is a family member. Fibers were used evidentially to take part in the crime solving by providing a link between the suspect, victims, and places and also showed the interaction of two or more surfaces between individuals or objects, as fibers from the suspect's clothes were found almost everywhere at the scene and even on the victim's bodies.

2.2 Pollen: small grains to discover the original death site

"Pollen is a fine powdery grain discharged from the male cone of a flower which usually appearing as yellow. It is potentially utilized in forensic applications as an important form of trace evidence in many criminal cases worldwide. Small in size, light, dry, and highly variable, it can be found on almost any object or individual that comes into contact with it or is exposed to the air around. Pollen is particularly useful in cases where there is a movement of objects or individuals from one location to another, or where a crime has been committed in an area with rare or unique plant species. (Alotaibi et al., 2020). Light microscopy is typically used for identification of pollen and spore types in cases. It is a high reliability and low-cost analytical technique in palynology compared to others. However, new technology for pollen characterization which can analyze the DNA of individual pollen grains, or determine the stable isotope ratio of carbon and nitrogen in pollen grains, Raman spectroscopy, and the application of scanning/transmission electron microscope may be practicable in the future." (Bryant, 2013)

Pollen grains
Source: *Science Photo Library*

Case story

In 2008, a 27-year-old woman, Mellory Manning, was assaulted and murdered while she was working as a prostitute in Christchurch, New Zealand. On 18 December 2008 she was picked up and taken to a property in the Avonside area where she was stabbed, strangled, and beaten with a metal pole resulting in her death. Her body was dumped in the nearby Avon River and found the next morning by a kayaker (Clarkson, 2014).

Case Investigation

Manning's body was discovered by a kayaker the next morning. Her watch had stopped at 11 o'clock, as a result of being submerged in the water. Her handbag with all her belongings was found over her shoulder. Over 30 officers conducted a crime scene search in order to find evidential items in or nearby the river. After a physical examination of the body, police confirmed that more than one weapon had been used in the attack that resulted in Manning's death. More than 900 people, including her clients and other prostitutes were interviewed, but no supporting information that could aid the investigation was found. DNA evidence was also collected from a carpark where Manning was known to take her clients.

After a nearby CCTV camera was examined for footage at around the time of Manning's disappearance, it was found that an Indian man, driving a blue four-wheel vehicle, may have been her last client. Seeds and pollens were found on Manning's clothing and in her nasal cavity suggesting a link to possible murder scene locations. In December 2010, it was announced that the Mongrel Mob hangout, a warehouse that was known to working prostitutes and run by the Mongrel Mob gang, was the scene of Manning's murder. This could be determined due to the characteristic examination of two-pored pollen grains recovered from her body that were also found at this location. Normal pollen grains contain a single pore, except in mutations caused by herbicide where more than one pore may be present. The pollen samples recovered from Manning's corpse were reexamined by comparing them to pollens collected from the suspicious warehouse. The samples from the two different locations exhibited similar characteristic and so were determined to have originated at the same source. This result showed that pollen embedded in Manning's clothing during her murder was solidly linked to Mongrel Mob's hangout warehouse (Macdonald, 2015). In September 2011, police announced that semen discovered on Manning's body did not match any of her known clients from that night. However, the

police did not exclude the possibility that Manning had an unknown sexual partner or client. As a result of the discovery of her death site, the police focused their investigation on Mongrel Mob's gang members.

On 29 March 2012, Mauha Huatahi Fawcett, a 24-year-old unemployed man, was arrested and charged with the kidnapping and murder of Mellory Manning. Even though his DNA did not match the semen sample found at the scene, he was living in Christchurch at the time and was found to be associated with the crime scene.

After his arrested, Fawcett was questioned by police. He told them that he was a member of another gang, but he wanted to join the Mongrel Mob gang To receive his patch to enter this gang he had been ordered to take part in the killing of Manning, who was in debt to the gang. Fawcett confessed to forcing Manning into a car and showing her a threatening text from another gang member. Fawcett said that although he had been ordered to stab Manning to earn his patch he had backed out. Manning was ultimately strangled, stabbed, raped, and beaten with a metal pole. She died from her injuries and Fawcett was accused of dropping her body into the nearby Avon river.

Case trial and conviction

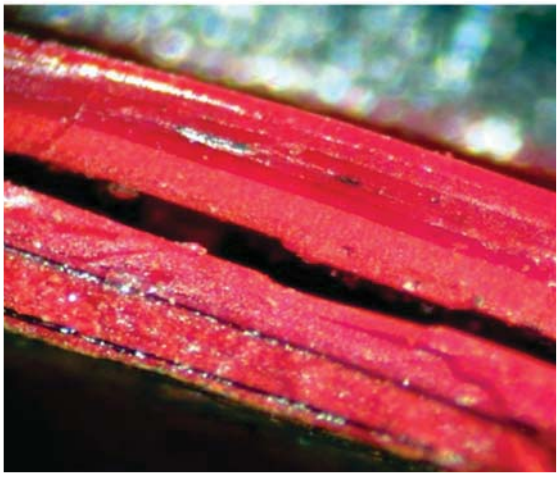
The trial began in February 2014. Fawcett carried out his own defense and claimed police had forced him into making a confession. In March 2014, a jury of 6 men and 6 women found Fawcett guilty of murdering Manning. In May, Mauha Huatahi Fawcett, who almost become a member of the Mongrel Mob gang, was sentenced to life in prison with a minimum non-parole period of 20 years for his part in the murder of Mellory Manning. After his sentencing, police said it was not the end of the investigation, as there are others definitely involved in Manning's death. However, as of yet nobody else has been charged over the crime (Bayer, 2014).

In this case, pollen played a crucial role as a forensic trace evidence in helping investigators narrow the search of the suspect's location. Pollen evidence has been used in many criminal cases to present to judges and juries how pollens can link suspects and victims to a mutual location (Horrocks & Walsh, 1998). It can be concluded that a rare pollen with special characteristics can be a powerful tool to help solve crime by linking the victim to a location and lead a criminal investigation successfully.

2.3 Paint: a perfect match of pink color

"Paint refers to a colored liquid substance that is applied by spreading over the surface and dries into a hard coating. It can be made in many colors and in different types. It is usually used as a decorative or protective coating from the effect of environmental conditions on various surfaces. Paint is also used to provide textures or colors on objects. It is considered a potential trace evidence in solving crime. It is particularly used in comparison of paint found at the scene and a sample of paint from a suspected object (Caddy, 2001). *According to forensic paint analysis and comparison guidelines of the scientific working group on materials analysis*

(SWGMAT), the analysis of physical and chemical properties of paints including binders, pigments, and additives can be performed using several techniques such as solvent/microchemical tests which are used to discriminate between paint films of differing pigment and binder composition that similarly exhibit in visual and macroscopical appearance. Pyrolysis gas chromatography is used for identifying and comparing the binder portion of samples. Polarized Light Microscopy (PLM) is used to examine paint layer structure in many forensic laboratories. X-ray fluorescence (XRF), X-ray diffraction (XRD) and Scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDS) are used to characterize and classify the morphology and elemental composition of paint samples. In addition, Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy are effectively used to examine paint fragment, binders, inorganic pigments, and additives used in coatings." (Scientific Working Group on Materials Analysis, 2000)



Paint fragment (Cross Section)
Source: *Paint fragment investigation, Cellmark Forensic Services*

Case story

Vicki Lynne Hoskinson, an 8-yearold girl, went missing on Monday, September 17, 1984 after asking her mother if she could ride her pink bike to a nearby mailbox to send a birthday card to her aunt in Tucson, Arizona. After waiting 20 minutes for her to return, her mother became concerned and asked her sister to go out and look for her. The sister found Vicki's bike lying abandoned on the side of the road a few blocks from her house, and one block from the elementary school. On hearing this, her mother rushed to where the bike was found and put it in the trunk of her car. She then called the Sheriff's Department and reported her child missing.

Source: On April 12, 1985, a woman hiker found a small human skull in the Tucson desert while walking her dog about 32 kilometers from the site where Vicki's bike had been found. Dental records confirmed they were Vicki's remains. Due to extreme damage to the remains, the cause of her death could not be determined (Smith, 2020).

Case Investigation

Investigators performed a search for Vicki and looked for any evidences nearby the elementary school where her bike was found. They also interviewed people including children in the nearby neighborhood. One witness, a teacher at the elementary school, told the investigators that he noticed a suspicious driver parked in a vehicle near the school on that day. Due to the strange behavior of the driver, a teacher had written down the California license plate number of the vehicle and later gave it to the police

after hearing about the missing girl. Other witnesses also saw the same driver in the area close to the scene and said he had made obscene gestures when he drove passed by their house (Wiley, 2020).

A trace on the California license plate number led to Frank Jarvis Atwood, a 28-year-old Californian man who was free on parole for child kidnapping and molestation charges in California. Frank Jarvis Atwood was arrested ten days after Vicki was last seen. After questioning, he told investigators that he was staying at a park in Vicki's neighborhood on September 17, the day she disappeared. He left the park to buy drugs around 3.00 pm and returned 2 hours later with visible bloodstainson his hands and clothing. He said he had fought with a drug dealer and stabbed him. Investigators searched Atwood's vehicle and found bloodstains on a blanket and a hairbrush. Blood, hair, and fiber tests were performed on those items but there was no proven link between him and Vicki's disappearance. A weapon such as knife, or suspicious clothing was never recovered. The only piece of evidence found that associated Atwood to Vicky's disappearance was a trace of pink paint and an impression on his car's bumper. According to forensic experts, after comparison, the pink paint recovered from the front bumper was matched perfectly to the color of Vicki's bike. In addition to that, traces of nickel plating from the bumper were also found smeared on the bike (Chase, 2018). At the site where the bike was found, investigators noticed damage to a mailbox post around 30 centimeters above the ground, consistent with the height of Atwood's vehicle, and this was believed to possibly be the point where his car hit Vicki's bike at a slow speed.

Case trial and conviction

The first trial took place on January 19, 1987. Frank Jarvis Atwood was found guilty of the abduction and murder 8-year-old Vicki Lynne Hoskinson. He was convicted by a jury on March 26, 1987. On May 8, 1987 he received a sentence of death for the first-degree murder charge and life in prison on a kidnapping charge.

In summary, this case demonstrates the importance of paint as a form of trace evidence that can reveal a lot of significant information during forensic investigations and help in solving crime. In research literature, paint chips and smears are often left as physical evidence at hit-and-run or other accidental cases (Kumar, 2018). During the physical interaction between two vehicles, paints can be transferred from one vehicle to another or in some cases paint can be transferred from a vehicle to a person who has been struck. In the case of Vicki Hoskinson,the pink paint found on the suspect's car ultimately led to his conviction.

2.4 Glass: tiny pieces as a key to unlock the mystery

"Glass is a fragile, non-crystalline inorganic solid substance typically transparent made of silica sand by melting it at high temperature and cooling rapidly to prevent crystal formation. It is widespread used in the building construction,

automotive components, eyeglasses, housewares, and telecommunications. Broken Glass is often encountered at crime scenes as a crucial physical trace evidence especially in the case of hit-and-runs, motor vehicle accidents, car theft, burglaries, kidnappings, murders, and many other types of crime. Glass fragments can be used to establish a link between a suspect, victim, and crime scene (Caddy, 2001). *Various techniques for glass examination are applied to most types of glass, including flat glass used for windows, doors, display cases, and mirrors, container glass, tableware glass, optical glass, decorative glass, and specialty glass used for headlamps, cookware, and others. In forensic works, glass examinations involve a comparison of samples from known and questioned sources to determine if they originated from the same sources. Glass is an isotropic material which can be identified and characterized by polarized light microscope (PLM). It can be distinguished from plastic by organic solvent solubility test and relative hardness examination. Elemental analysis of glass can be measured by X-ray fluorescence spectrometry (XRF), scanning electron microscopy-energy dispersive X-ray spectrometry (SEM-EDS), inductively coupled plasma-optical emission spectrophotometry (ICP-OES), and inductively coupled plasma-mass spectrometry (ICP-MS)."* (Scientific Working Group for Materials Analysis, 2005)

Broken Glass
Source: *Science Photo Library*

Case story 1

At 9:30 pm on a dark night in February 1987, Mr. Craig Elliott Kalani, a 19-year-old man, went for a walk with his dog in his neighborhood in northwest Oregon and never returned home. He was declared dead resulting from a hit-and-run.

Investigators found pieces of glass embedded in his jacket and on the ground around his body at the scene. A search for a possible vehicle with damage caused by a hit-and-run accident led to the discovery of Ms. Susan Nutt's car. Broken glass fragments that had been recovered from Craig's jacket as well as those collected from the crime scene were scientifically compared to the glass on Ms. Nutt's car. Refractive index tests of the glass samples from the two different sources were performed by scientists at Oregon State University's Radiation Center. The results exhibited that the glass fragments

collected from the scene contained the same twenty-two chemical compositions as those found from the windshield glass on Ms. Nutt's car. The glass samples from the two different sources were confirmed to be a definite match.

Eventually, these pieces of glass helped to convict Ms. Susan Nutt of hit-and-run resulting in the death of Mr. Craig Elliott Kalani. Ms. Nutt failed to perform the duties of a driver for an injured person and she received a prison sentence of up to five years (Bertino & Bertino, 2015) .

Case story 2

In the early morning of August 11, 2000, the body of Tracy Tomko, a 22-year-old financial analyst in Akron, Ohio, was found lying in a puddle of water near her apartment. After an initial crime scene search, investigators found a few tiny glass fragments and a piece of quarter-sized plastic left at the scene. From the discovery of the small piece of plastic, investigators spotted a 1990 Ford Tempo with a suspicious piece of plastic missing.

After questioning the owner of the car, Ralph Blackwood, a 38-year-oldman from Akron, it was found that he had gone out of state to get a replacement windshield the same day that Tomko's body was found. After further questioning and being presented with the broken glass and plastic evidences linking him to the scene, Ralph Blackwood finally confessed to killing Tomko. He said that he had accidentally struck Tomko with his car causing her death while she was on her morning run near her apartment at about 6 am. Ralph Blackwood pleaded guilty to involuntary manslaughter, tampering with physical evidence and hit-and-run driving. He was sentenced to 10 years in prison for his crimes (Carloss, 2018).

According to case studies, glass evidence has shown its value and effectiveness as a physical trace evidence in the support of criminal investigations. It is most commonly used in a comparison of glass fragments from two or more different sources in order to determine if they have originated from the same source. Glass is said to be a transparent witness and a very important forensic evidence used in connecting people, objects, and places. The proper interpretation of glass evidence including the weight and strength of evidence is also a key factor to help explaining and demonstrating to judges and juries the value of the evidence relevant to the crimes (Curran et al., 2020). Thus, glass is used successfully in helping to solve many crimes worldwide.

2.5 Soil: fine and powdery soil to solve a double murder case

"Soil refers to complex mixtures of substances such as minerals, water, air, organic and inorganic materials, as well as organisms typically found on the surface of the earth. It is usually a major natural nutrient source for the growth of plants. In forensic context, soil is particularly used as a piece of contact trace evidence to associate soil samples taken from suspect/victim or objects such as shoes, clothing, weapon, or vehicle from one location to another location which significantly can be used to provide great information to help in criminal investigations (Pye, 2007). *In general, many forensic labs use spectroscopic techniques such as visible*

microspectrophotometry (MSP) and Attenuated Total Reflectance (ATR) Fourier Transform Infrared spectroscopy (FTIR) for discrimination of soil samples based on their organic and inorganic components (Woods Brenda et al., 2014). *For elemental analysis of soils, X-ray fluorescence spectroscopy (XRF) and scanning electron microscopy/ energy dispersive X-ray spectroscopy (SEM/ EDX) are frequently used in forensic laboratories to detect differences in the elemental compositions of soil specimens."* (Woods et al., 2014)

Microscopic analysis of soil sample
Source: *Science Photo Library*

Case story

On the evening of Monday, September 18, 2000, police in Adelaide, South Australia received a call from a man reporting that his wife, mother, and son were missing. Bloodstains and broken glass were found on the floor of a room and there were towels, a blanket, and a pillow missing from his son's bedroom. His wife's car, a silver Toyota Cressida, was gone as well.

A day later, police found the car broken down and abandoned on a road 200 kilometers from the house. Investigators performed a search of the car and found clear bloodstains on the exterior of the trunk and a rear numberplate. Inside the trunk, a pine post and a bloodstained shovel with powdery soil on both sides of it were found. Inside the car, bloodstained towels, a bloodstained knife, bedding, a green bracelet, a pile of wooden sticks and a pair of boots coated with fine soil were discovered (Porter, 2007).

Case investigation

After discovering the car, police arrested Matthew Holding, a 22-year-old man, and charged him with the double murder of his mother and grandmother. He refused to answer any questions from police. Since the bodies of the two victims had not yet been discovered, investigators needed to find scientific evidences that could locate where the bodies were hidden. From the evidences found in the car, investigators suspected a shovel was used to bury the victims. Soil samples recovered from the shovel, bracelet, and boots were examined for morphological characterization and chemical compositions. According to soil forensic experts, the soil morphology and chemical compositions led them to focus on a quarry area. The color and material structure of soil samples collected from the quarry area produced an identical match to those sample from the shovel, bracelet, and boots. Investigators spent several days searching for the bodies in the area of quarry. On Monday, October 9, 2000, three weeks after the murders, two bodies were found in a wet area of the quarry, 15 meters from where the control soil samples were collected (Fitzpatrick & Raven, 2012).

Case trial and conviction

Mr. Matthew Holding confessed that he killed his mother and grandmother by slitting their throats because they refused to give him a cigarette and lectured him about smoking. While loading their bodies into the trunk of the car he found that his mother was still alive so he struck her with a pine post until she died. Later, he cleaned up the house and drove out to the quarry. He used a shovel to bury their bodies in that area. Due to the strength of the trace evidence presented in the Supreme Court, Mr. Matthew Holding pleaded guilty to the murders of his mother and grandmother and received a life sentence in prison.

This case illustrates the value of soil evidence in a murder case. The soil materials and compositions can help investigators to link a suspect's activities with a specific location. Soils have a unique chemical profile that can be differentiated based on morphological appearance, geological features, chemical, biological, and physical composition. Soils from different areas exhibit significantly different chemical and physical properties (Uitdehaag et al., 2017). This unique profiling makes soil an essential trace evidence in criminal cases.

CONCLUSIONS

This paper has reviewed the value of trace evidence and highlights its impact in forensic science and the criminal justice system. The case studies included demonstrate how a tiny piece material like a fiber, pollen, paint, glass, and soil have been scientifically applied in criminal cases. Trace evidence has played a crucial role in establishing a potential link between a suspect and a victim at the same scene or to a specific time or position. In the past 20 years, there has been the development of DNA databases Today, forensic evidence, especially DNA and fingerprints are extensively used to both convict and exonerate defendants in criminal cases.

However, DNA is not always probative and left behind at the scene of a crime Therefore, trace evidence, non-DNA evidence, may be the only pivotal source of scientific evidence that can provide useful investigative information. Trace evidence helps detectives, law enforcement officers, and investigators around the world piece together clues to solve crimes.

Trace evidence can be successfully used to reconstruct crimes, describe the story of what had happened, and who was involved. Despite not always being visible to the naked eye, difficult to examine and analyze at times, and needing professional knowledge, its specific chemical and physical properties make trace evidence a strong, valuable, and unique resource in any criminal proceeding. Trace evidence used as forensic evidence is a powerful tool for use in the criminal justice system.

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