T. Kahana,[1] Ph.D.; J. Almog,[1] Ph.D.; J. Levy,[1] B.A., E. Shmeltzer[1]; Y. Spier[2]; and J. Hiss,[3] M.D.

Marine Taphonomy: Adipocere Formation in a Series of Bodies Recovered from a Single Shipwreck

REFERENCE: Kahana T, Almog J, Levy J, Shmeltzer E, Spier Y, Hiss J. Marine taphonomy: adipocere formation in a series of bodies recovered from a single shipwreck. J Forensic Sci 1999;44(5): 897–901.

ABSTRACT: Taphonomy of marine environments has been studied mostly from individual cases. The formation of adipocere, or "grave-wax," is an important indicator of the postmortem interval.

In the present paper, the conditions and the timing of adipoceric formation are observed in a series of 15 cadavers recovered at different times, over a period of 433 days, from the same contained environment. Initial foci of adipocere on the subcutaneous tissue of the cadavers were detected as early as 38 days from the time of immersion in cold (10–12°C) sea water. The discrepancies between our findings and previous reports on the correlation between time since death and decomposition stages in marine environments are discussed.

KEYWORDS: forensic science, forensic pathology, taphonomy, adipocere, postmortem interval, marine environment

Establishing time since death is an important task in medico-legal investigations; the longer the postmortem interval, the more difficult it is to assess the time of death. The estimation of this interval is based on the totality of processes that affect the preservation of the cadaver (taphonomy). Environmental factors like temperature, fauna, and the medium in which the human remains are located greatly affect their taphonomy (1). Documentation on postmortem changes in marine environments is scant and mostly based on individual case reports (2–5). In the present paper, we present an account of the progressive postmortem changes in a sample of 15 individuals who perished in a shipwreck.

On June 22, 1995 the Belgian flag cargo ship *Mineral Dampier* sunk after colliding with the Korean *Hungin Madras* in the East China Sea, 250 miles south of Nagasaki. On board the *Mineral Dampier* were 27 seamen, ten Filipinos, nine Israelis, five Rumanians and three Belgians.

Although the search for survivors commenced as soon as the accident was reported (4 h after the collision), only two cadavers were recovered on the first night by Japanese fishermen, the rest of the crew were assumed to be still within the sunken ship.

Repatriation and proper burial of cadavers is considered a sacred duty in the Jewish religion. Because of the religious feelings of the family members of the Israeli sailors missing at sea, the Israeli Ministry of Transport, along with the Israel Police joined forces to recover and identify the victims of the *Mineral Dampier* wreck. Over a 15-month period, a crew of professional divers undertook two diving expeditions using mixed gas systems and three expeditions using saturation diving systems to search the inner part of the wreck. Thirteen bodies in various stages of decomposition were recovered, immediately stored at freezing temperature and latter on embalmed. A total of 15 victims were repatriated.

Materials and Methods

Seek and retrieval of the cadavers from the *Mineral Dampier* was an enormous logistic endeavor. A marine engineering company, Oceana Marine Research Co. was contracted by the Israeli Ministry of Transportation—Maritime Administration, to undertake the project.

Data collected from various sources lead sonar searches to the wreck site, which was confirmed by the presence of fresh petrol leaks from the ship tanks. The sunken vessel was located at 30° 32′ 36.51″ N and 126° 23′ 38.54″ E by a small submarine launched to establish positive identification of the ship, which was lying, broken in half at about 85 m from the surface (under a pressure of 9.5 atmospheres). The area is known for its rough sea conditions with frequent typhoon storms, limiting the possibility of long and safe diving sessions.

The bodies of the missing seamen were assumed to be mostly on the middle deck of the ship, at a depth of 65 m. The temperature of the water at that level was carefully recorded prior to each dive, since the divers' suits required a specially controlled heating system to avoid hypothermia. Furthermore, the currents around the wreck were periodically noted, to plan for the trajectory of the divers.

The divers performed some 120 surface support dives, over a 15-month period. Every few months the team moored the diving support ship atop the wreck, the divers went down, and after exhaustive searches, lifted the remains in a special basket to the surface.

The recovered bodies were immediately stored at −20°C on board the diving mother ship and transported to a hospital in the Korean Port of Pusan, where initial examination, including photo and radiographic documentation was conducted for identification purposes. The cadavers were then embalmed to avoid further decomposition prior to being airlifted to Israel. Further analysis of the findings was conducted at the National Center of Forensic Medicine in Israel. A complete necroscopic examination including, histology was performed. No chemical analysis was carried out since the remains were embalmed.

[1] Division of Identification and Forensic Science (DIFS), Israel Police, Head Quarters, Jerusalem, Israel.
[2] Oceana Marine Research Company, Petach Tikva, Israel.
[3] The L. Greenberg Institute of Forensic Medicine, Tel-Aviv, Israel.
Received 13 Oct. 1998; and in revised form 11 Jan. 1999; accepted 18 Jan. 1999.

Results

A total of 15 bodies were recovered at various stages of the rescue operation. Since the collision occurred during the summer season at 02:00 h, most of the crew on the vessel was wearing only light clothing.

The day following the accident, two cadavers were found floating in the vicinity of the site. The temperature of the water was between 20–24°C, and the air temperature was about 29°C. The bodies showed slight maceration of facial skin and "washerwoman" hands and feet. A few scattered abrasions and subcutaneous hemorrhages were visible. Rigor mortis was present only in the lower limbs and the distribution of livor mortis was not remarkable. Cranial, intra-thoracic and intra-abdominal organs were well preserved. Severe pulmonary edema was present, no other acute or chronic pathology was detected except for fractures of long bones of lower limbs (Table 1).

Subsequently, 13 cadavers were retrieved from the wreck. Nine cadavers were recovered from the middle deck at 65 m from the surface. The temperature at this depth ranged between 10–12°C. A 24 h cyclical underwater current of 2.5 knots was measured, the current was stronger during full moon periods. Another four bodies were recovered from the lower deck at 80 m from the surface, where the temperature was 10°C. No fauna was found within the ship, probably because of low oxygen content due to the iron ore oxidation of the ship's cargo. Around the wreck a great number of crustaceans were reported by the divers, but none were detected in the vicinity of the cadavers.

Twenty-five days after the accident, three cadavers were recovered by the divers.

The main postmortem changes observed on these bodies were marked bloating mainly of the face and scrotum, extensive marbling, reddish discoloration of face and chest, green discoloration of the abdomen and slippage of the skin of hands and feet. The subcutaneous tissue of face and trunk had a somewhat unctuous, waxy consistency (Fig. 1a-b). The thoracic and abdominal cavities contained small amounts of dark decomposed purge fluid and the internal organs were well preserved. Thirty-eight days following the incident one cadaver was recovered from this same area. The facial features were still conserved despite the extensive bloating of the face; the eye globes and tongue were soft and protruding. Subcutaneous adipocere could be observed mostly on the face and lower abdomen of the cadaver. On histology the tissue appeared as an intermeshed network of fibers, embedded in a homogenous disorganized fatty substance (6). Most of the skin was dark gray-brown. Glove-like slippage of the skin of hands and feet was detected and the whole body was almost hairless, multiple foci of saponification

TABLE 1—*Successive taphonomic changes in immersed cadavers.*

Time Since Death	Number of Bodies	Postmortem Changes
2 Days	2	Washerwoman's hands
25 Days	3	Bloating, marbling, slippage
38 Days	1	Bloating, slippage, dark gray-brown discoloration, focal adipocere, purge fluid in body cavities
68 Days	2	Bloating, slippage, dark gray-brown discoloration, extensive subcutaneous adipocere, purge fluid in body cavities
109 Days	3	Total saponification covered by a thin friable crust
433 Days	4	Total saponification with thick friable crust and skeletonization

FIG. 1—*Early decomposition of a fully clothed cadaver recovered 25 days after the wreck. a. Bloating of face. b. Marked marbling and initial slippage of skin.*

were visually and histologically detected in the subcutaneous facial and abdominal tissue (Fig. 2a-b). The brain was nearly completely liquefied. The intra-thoracic and intra-abdominal organs, except the spleen, were well preserved. The splenic tissue was soft and amorphous. Between the intra-pleural and intra-peritoneal organs, decomposed fluid was present.

Sixty-eight days from the day of the accident, two more cadavers were retrieved from the middle deck. Bloating and dark discoloration similar to the previous stage was observed. The main difference was the consistency of the skin, which was easily shed by the slightest manipulation, exposing large confluent patches of adipocere. The stage of preservation of the internal organs was comparable to those of the cadaver recovered one month earlier. Large quantities of purge fluid emanated from nares and mouth.

One hundred and nine days after the disaster, three cadavers were retrieved from the middle deck. By this time, all the soft cutaneous and sub-cutaneous tissue has been transformed into a yellow-whitish, sticky material with a thin, slightly darker hardened cortex. The outer crust was very friable. The internal organs had some superficial adipoceric homogenous formation, although they retained their morphology. Initial skeletonization could be observed on the lower extremities (Fig. 3a-b).

The final expedition was launched 433 days after the disaster. Four cadavers were recovered from the lowest deck. Three corpses found in an open cabin were skeletonized with very few remnants of adipoceric tissue. One body was recovered from a closed cabin, where there was no underwater current. Most of the cutaneous and sub-cutaneous tissue was present in adipoceric form, completely covered with a thick hardened crust (Fig. 4a–b).

Discussion

Establishing the postmortem interval in submerged cadavers poses some difficulties. A number of interacting variables, like temperature of the water, depth of immersion (resurfacing), fauna, currents and clothing of the victim have an effect on the taphonomy (1).

In the present study the temperature of the water at the depth where the cadavers were found (65–85 m) was 10–12°C. All but one of the cadavers (Fig. 1a) recovered were clothed in very light garments, thus the body temperature was immediately affected by that of the water. The divers in charge of recovering the bodies reported a complete absence of fauna within the wreck, although some crustaceans were seen around the ship. Strong underwater currents (2.5 knots) were measured around the wreck, but only three cadavers were exposed to it, all other victims retrieved from the ship were found in enclosed spaces.

The first two cadavers in this series were found floating on the

A B

FIG. 2—*Moderate decomposition, 38 days after immersion. a. Well preserved facial features despite bloating of face. b. Glove-like slippage of hands.*

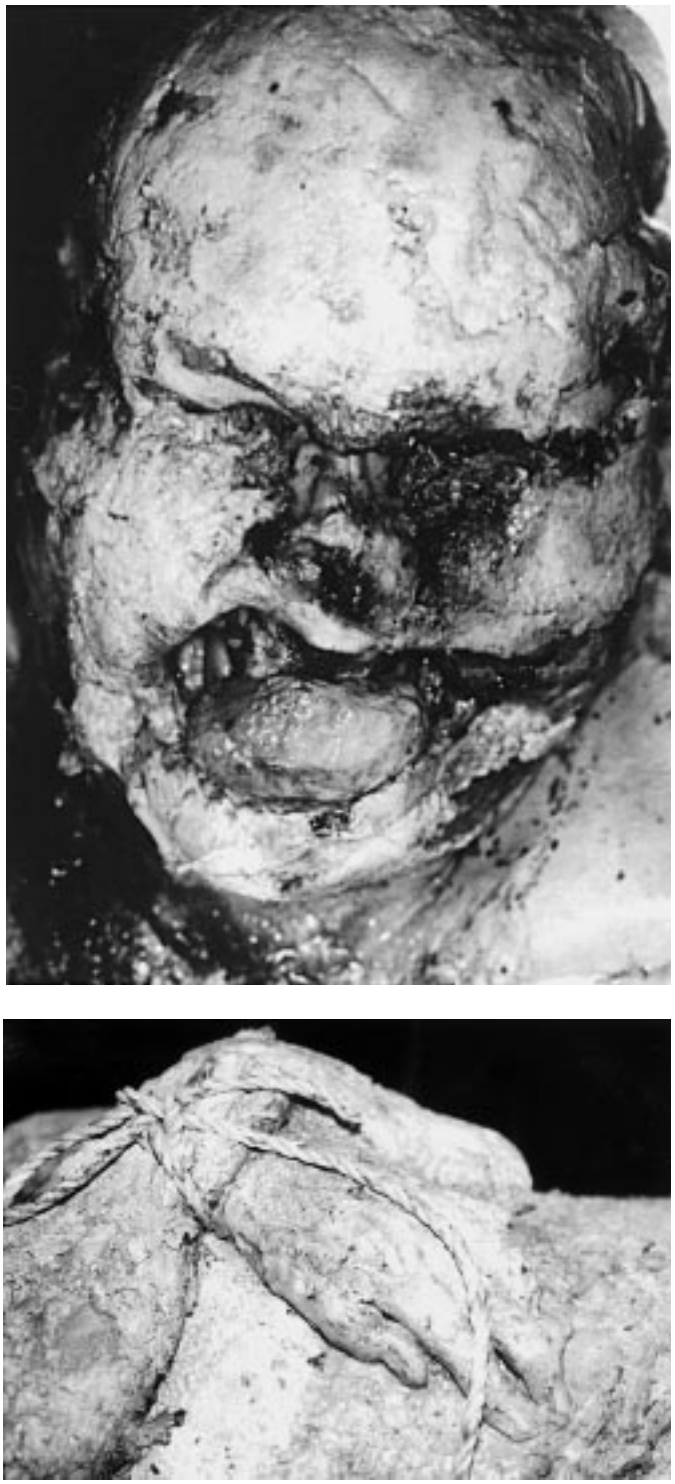

FIG. 3—*Total saponification of victim 109 days after drowning. a. Good conservation of soft tissue facial morphology. b. Good conservation of morphology of hands (the ligature around the wrists was used to facilitate the retrieval from the wreck).*

surface, while the remaining bodies were lodged within the debris of the sunken vessel, and they never resurfaced. When the environmental conditions in which a body is submerged are known, the rate of formation of adipocere, can be a good indicator of the postmortem interval (7).

Adipocere is a waxy, byproduct of decomposition, associated with wet and warm environment (8) formed by the hydrolysis and hydrogenation of tissue fats. It is composed of hydroxy fatty acids, predominantly 10 hydroxy stearic acid (9). In the human, the most common unsaturated fatty acids are oleic, linoleic, and palmitoleic acids, the saturated fatty acids found in highest proportion are palmitic and stearic acids (7).

Recent research has shown that the presence of high quantities of oleate salts may be favorable for solidification of decomposing tissues, a common feature of adipocere (10). Once formed, adipocere can remain unchanged for as long as 150 years (11). The degradation of adipocere appears to depend on the presence of gram positive bacteria from the burial environment (9). On histological examination, adipocere appears as a confused network of fibers cemented by a white fatty-looking substance without trace of organized or recognizable structure (6).

It has been suggested that adipocere formation occurs within a limited temperature range, generally tied to the optimum growth temperature of the bacterium Clostridium perfringens (welchii). O'Brien (1997) believes that this optimum temperature ranges between 21°–45°C (12).

The rate of development of adipocere in immersed cadavers has been tied to the temperature of the water. Most authors report initial adipoceric formation in cold water (4°C) not earlier than 12 to 18 months after immersion (13), in lukewarm water (15°–22°C) between two-three months after immersion (7), and in one to three weeks after immersion only under extremely warm conditions (14).

In the present case, early decomposition was retarded by the low temperature of the water (10°–12°C), and because the bodies remained trapped within the wreck and never resurfaced. The decomposition sequence seen in this study conflict with that reported by Boyle et al. (1997) for the Monterey Bay area, for the appropriate period of time. In their sequence the phase described, as "early decomposition" (up to one week) (5) was concordant with the preservation of the cadavers recovered from the *Mineral Dampier* 25 days after the wreck.

The assumption that adipocere formation is hastened by higher temperature of the water (2,7) seems to be contradicted by the findings of the present investigation. Initial foci of adipocere formation were visually and histologically detected as early as 38 days after the incident, while other investigators report initial adipoceric formation in cold water not earlier than 12–18 months (365–540 days) (7). Furthermore in our series, saponification limited to the subcutaneous tissue was already observed after 68 days, and extensive adipoceric formation covered by a thin hard crust was detected 109 days after immersion. On the final retrieval expedition (433 days after death) the consistency of the adipocere was hard and friable.

Skeletonization of remains was observed in three cadavers recovered during the last dive. The absence of soft tissue could be explained by the effect of the strong currents encountered in this area of the wreck. Scavenging by marine life is discarded as a contributing agent in the skeletonization since a total absence of fauna within the ship was reported by the divers, and this report was confirmed by the lack of any scavenging marks on the retrieved bodies.

The pace of adipocere formation perceived in the present series of cadavers does not coincide with previously published data on aquatic taphonomy (15). These differences merit further investigation into the formation of adipocere to establish a reliable "taphonomic clock" in marine environments.

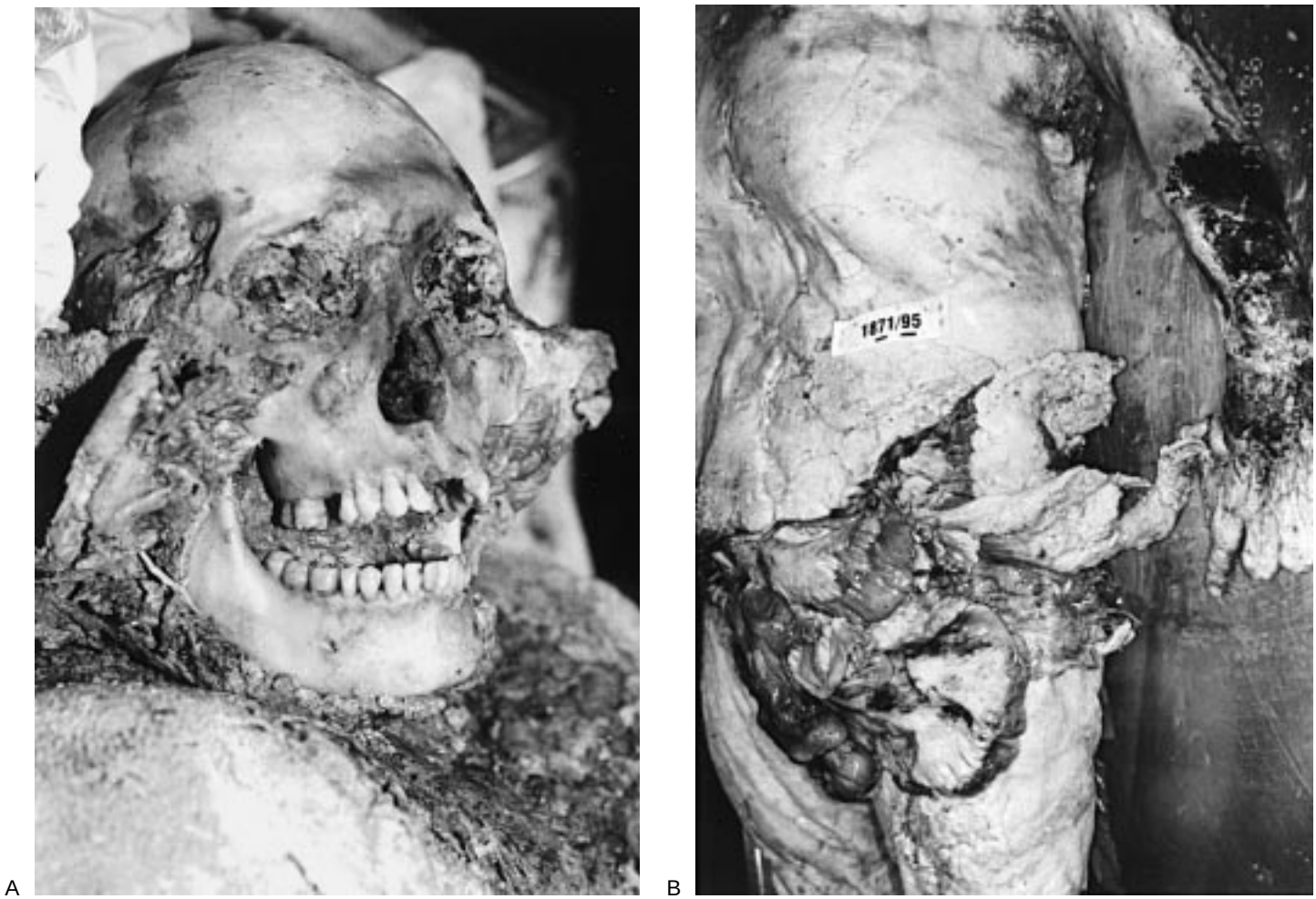

FIG. 4—*Complete adipoceric formation following 433 days of immersion. a. Exposure of facial skeleton through residual adipocere. b. Saponified, well preserved intra-abdominal organs exposed through a tear in abdominal wall produced during the rescue operation.*

References

1. Sorg MH, Dearborn JH, Monahan EI, Ryan HF, Sweeney KG, David E. Forensic taphonomy in marine contexts. In: Haglund WD, Sorg MH, editors. Forensic taphonomy—The postmortem fate of human remains. Boca Raton: CRC Press 1997;567–604.
2. Cotton GE, Aufderheide AC, Goldschmidt VG. Preservation of human tissue immersed for five years in fresh water of known temperature. J Forensic Sci 1987;32:1125–30.
3. Giertsen JC, Morild I. Seafaring bodies. Am J Forensic Med Pathol 1989; 10:25–7.
4. Haglund WD. Disappearance of soft tissue and the disarticulation of human remains from aqueous environments. J Forensic Sci 1993;38:806–15.
5. Boyle S, Galloway A, Mason RT. Human aquatic taphonomy in the Monterey bay area. In: Haglund WD, Sorg MH, editors. Forensic taphonomy—The postmortem fate of human remains. Boca Raton: CRC Press 1997; 605–13.
6. Simpson K. Death and postmortem changes. In: Taylor's principles and practice of medical jurisprudence. 12th ed. London: J&A. Churchill Limited 1965;70–103.
7. Mellen PFM, Lowry MA, Micozzi MS. Experimental observations on adipocere formation. J Forensic Sci 1993;38:91–3.
8. Rothschild MA, Schmidt V, Schneider V. Adipocere—Problems in estimating the length of time since death. Med Law 1996;15:329–35.
9. Pfeiffer S, Milne S, Stevenson RM. The natural decomposition of adipocere. J Forensic Sci 1998;43:368–70.
10. Cabirol N, Pommier MT, Gueux M, Payen G. Comparison of lipid composition in two types of human putrefactive liquid. Forensic Sci Int 1998;94: 47–54.
11. Polson CJ. The signs of death. In: Polson CJ, Gee DJ, Knight B, editors. The essentials of forensic medicine. 4th edition. Oxford: Pergamon Press 1985;23–6.
12. O'Brien TG. Movement of bodies in Lake Ontario. In: Haglund WD, Sorg MH, editors. Forensic taphonomy—The postmortem fate of human remains. Boca Raton: CRC Press 1997;559–63.
13. Sledzik PS, Micozzi MS. Autopsied, embalmed, and preserved human remains: distinguishing features in forensic and historic contexts. In: Haglund WD, Sorg MH, editors. Forensic taphonomy—The postmortem fate of human remains. Boca Raton: CRC Press 1997;483–92.
14. Simonsen J. Early formation of adipocere in temperate climate. Med Sci Law 1977;17:53–5.
15. Reh H, Haarhoff RH, Vogt CD. The estimation of the time of death of corpses recovered from water. Z Rechtsmed 1977;27:261–6.

Additional information and reprint requests:
T. Kahana, Ph.D.
67 Ben Zvi Rd
PO Box 49015
Tel-Aviv 61490 Israel