CASE REPORT

Gerald E. Cotton,[1] *M.D.; Arthur C. Aufderheide,*[2] *M.D.; and Volker G. Goldschmidt,*[3] *M.D.*

Preservation of Human Tissue Immersed for Five Years in Fresh Water of Known Temperature

REFERENCE: Cotton, G. E., Aufderheide, A. C., and Goldschmidt, V. G., **"Preservation of Human Tissue Immersed for Five Years in Fresh Water of Known Temperature,"** *Journal of Forensic Sciences,* JFSCA, Vol. 32, No. 4, July 1987, pp. 1125–1130.

ABSTRACT: Two human bodies were recovered from the waters of the Duluth, Minnesota harbor. Extensive adipocere formation resulted in remarkable preservation of gross anatomic features of internal organs. Total time of immersion could be precisely estimated at five years. Water temperature during those five years could also be accurately estimated by direct measurements taken during the year following recovery of the bodies and from information supplied by a local electric power generating company. Immersion occurred at the time of the year when water temperature was highest (70°F [21°C]) facilitating the rapid formation of adipocere. A proposed mechanism for formation of adipocere is described.

KEYWORDS: pathology and biology, tissues (biology), submerged bodies

On 29 Aug. 1983, a lake freighter entered the Duluth, Minnesota harbor. While proceeding to dockage under windy conditions, the captain ordered an anchor be dropped to assure stability. Later when the anchor was raised, the crew was surprised to find an Oldsmobile Toronado impaled on the flukes. The badly damaged and flattened automobile contained the bodies of an adult male and female. The bodies were not easily removed because they were partially compressed and trapped by the flattened automobile body. The time and means by which the automobile was crushed is unknown. It is known, however, that ships commonly lower anchors weighing many tons in the area from which the vehicle was retrieved. It is likely that anchors had previously struck the automobile resulting in the observed damage.

Both the vehicle and the deceased persons contained in it were reported missing on 30 Aug. 1978, and, therefore, apparently had been submerged exactly five years in the ship canal of the Duluth harbor. This location, approximately 100 ft (30 m) from the Port Termi-

Received for publication 21 Aug. 1986; accepted for publication 24 Sept. 1986.

[1]Associate professor and head, Department of Clinical Sciences, University of Minnesota-Duluth, School of Medicine, Duluth, MN.

[2]Professor and head, Department of Pathology, University of Minnesota-Duluth, School of Medicine, Duluth, MN.

[3]Medical examiner, St. Louis County, Duluth, MN.

nal dock (Loran* C - GRI 8970. TDs 32614.8 and 45830.6) is about 1 mile (1.6 km) from the entry into the harbor from Lake Superior (see Fig. 1).

Necropsy Findings

At postmortem examination, parts of the hands and feet were missing. Extensive adipocere formation of the subcutaneous fatty tissue was found in all parts of the body including the face, neck, trunk, and extremities, but adipocere was not recognizable in the peritoneal or thoracic cavities. The skeletal muscles were quite desiccated and crumbly. The individual thoracic and abdominal organs appeared anatomically well preserved grossly. Histologically, their basic organ structure was recognizable, but nuclear staining had disappeared. The subcutaneous fatty tissue was also structurally recognizable histologically. The brain demonstrated normal surface contours, but its consistency was very soft and paste-like with complete loss of histologic basic nuclear staining although occasional cholesterol crystals were identified in the sections. Chemical tests of liver, subcutaneous tissue, and gastric content for alcohol and narcotic drugs were nonreactive. There was no odor of decomposition.

After five years of immersion, these bodies presented the appearance of a superficial shell of adipocere material encasing visceral organs demonstrating a high degree of retention of gross anatomic features but with substantial effacement of histologic structural details.

Water Temperature Measurements

That the immersed bodies were not skeletonized posed questions as to why adipocere had formed, resulting in the noted state of preservation. One measurable factor was water temperature at the site of immersion. One of us (GEC) measured the water temperature at various depths from the surface to the bottom the day following retrieval of the bodies and on the first day of each of the subsequent twelve months. Measurements were made with a Vexilar® Thermistor probe verified to be accurate within 1°F by a laboratory analytical thermometer. The probe was lowered by attaching it to a 10-lb (4.5-kg) lead weight on a fishing downrigger in summer and through a hole drilled in the ice in winter. In addition, through the coopera-

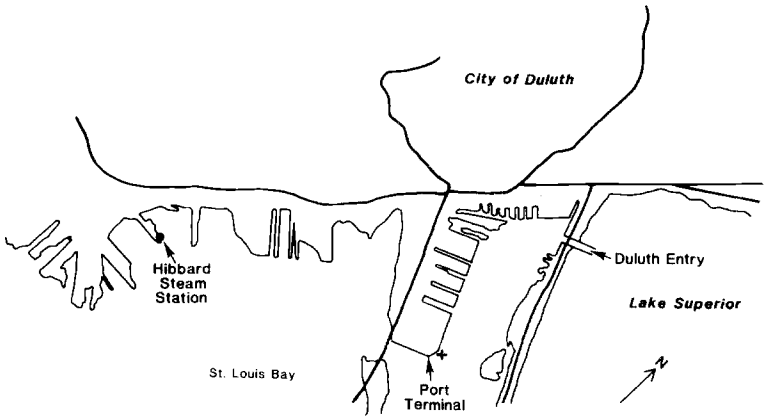

FIG. 1—*Harbor of Duluth. + is location of submerged vehicle.*

*LORAN—an acronym for long-range navigation—is a navigation system that determines a vessel's location using radio signals received from onshore transmitters.

tion of a local utility company, temperature readings taken at Hibbard Steam Station, an electrical power generating station located six miles (10 km) upstream on the St. Louis River, were available for most of four of the five years during which the bodies were submerged. As the temperature readings taken at the Hibbard Steam Station were virtually identical with those measured at the immersion site during the year following discovery of the bodies, it is possible to use the Hibbard Steam Station temperature records of the previous five years to predict the exact temperature experienced by the immersed bodies during those five years (see Figs. 2 to 4).

From the above, it is clear that the water at the site of immersion was essentially St. Louis River water and that at the time of immersion the water temperature was at its highest point during the year.

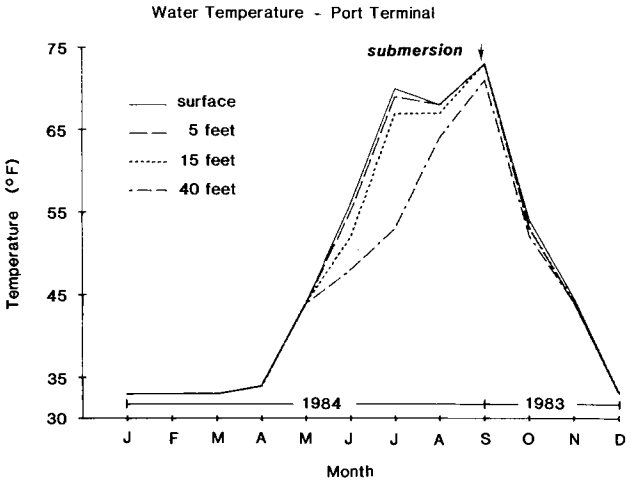

FIG. 2—*Water temperature for Port Terminal.*

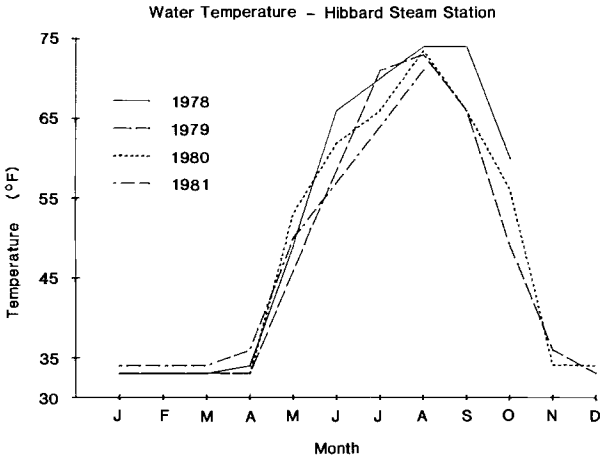

FIG. 3—*Water temperature for Hibbard Steam Station.*

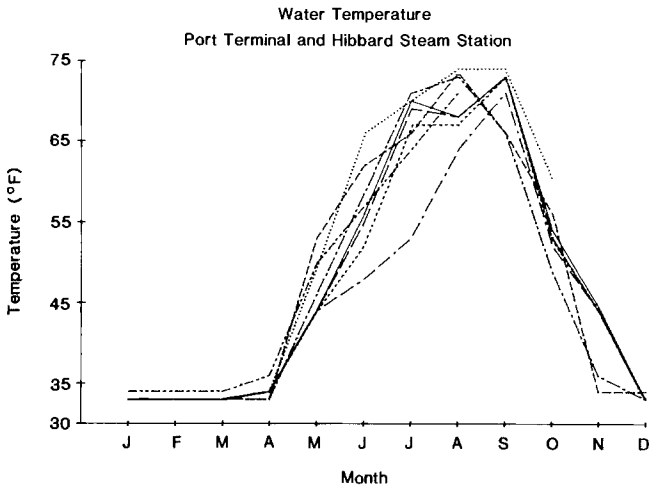

FIG. 4—*Water temperatures for Port Terminal and Hibbard Steam Station.*

Discussion of Adipocere Formation

Adipocere (adipo-"fat"; cere-"wax") is a postmortem chemical alteration of normal adipose tissue rendering it firm, grayish white, and of wax-like consistency. The earlier changes are superficial, involving lower dermis and subcutaneous tissue, but later mesenteric, perirenal, and paravertebral adipose depots also may be involved. Any body site housing fat tissue may undergo this change. Once formed, adipocere is relatively resistant to subsequent chemical change and thus it operates to preserve soft tissue [*1*].

Our understanding of physical and chemical mechanisms operating to produce this change is primitive but evolving. Early eighteenth century workers were limited largely to gross observations and mistakenly concluded that skeletal muscle underwent postmortem alterations, turning it into fat. Nineteenth century investigators identified preexisting normal fat as the only progenitor substance of adipocere and that fatty acids accounted for a large part of its composition. Workers in the first part of this century incorrectly assumed that calcium soaps of these fatty acids were responsible for the apparent stability of adipocere. Although earlier work had suggested immersion in water was required for adipocere formation, more recently Evans and others demonstrated its presence in bodies which had been placed in lead-lined coffins placed in sealed cement vaults above ground for 100 to 150 years [*1*]. Based on both observation in forensic science cases and some simple in vitro studies in 1957, Mant identified a series of variables influencing adipocere development (Table 1) [*2*].

Most recently Tomita [*3*] induced adipocere development in white mice immersed under varying conditions and subjected the resulting adipocere (and some from forensic corpses) to chemical analysis including gas chromatography. Combining his observations with some findings of earlier workers [*4-6*] led the authors of the present report to postulate the following sequence of events leading to adipocere formation:

1. During the first few days after death degradation of triglycerides composing neutral fat is initiated by endogenous lipases.
2. Postmortem putrefaction is initiated by growth of intestinal bacteria.
3. Bacterial enzymes then normally complete the conversion of neutral fat into fatty acids.
4. Other bacterial enzymes then convert some of these fatty acids into hydroxy fatty acids,

TABLE 1—*Effect of physical and chemical variables on adipocere production.*

Effect*	Factor
+	initial presence of fat
-	elapsed time between death and burial
-	autopsy performed before burial
-	body enclosed in coffin
+	body clothed
-	straw in bottom of grave
0	access of air to body after burial
+	mass burials
+	bacterial putrefaction
+	humid warmth

* adipocere development enhanced (+), inhibited (-), no effect (0)

Table created from observations narratively recorded in Mant and Furbank.[2]

mainly 10-hydroxystearic acid; oleic acid appears to be the primary source of this compound and *Clostridium perfringens* may be the principal operative organism.

5. The hydroxy fatty acids have a high melting point and contribute stability to adipocere.
6. Some of the fatty acids are also polymerized into dimers and oligomers.
7. The low pH (4.5 to 5.5) produced by the fatty acids stops bacterial growth and at least in vitro becomes a self-sterilizing process, arresting putrefaction and contributing further to adipocere's stability.

The effect of temperature on adipocere has been commented upon in only the most general way and information concerning this variable usually needs to be estimated in forensic science cases [*7*]. On the basis of the season at time of burial, Mant suggested cold inhibits adipocere formation [*2*] while others have noted earlier onset of such adipocere development in the tropics [*8–10*]. Rapid onset of adipocere (one to three weeks) has also been reported in a body immersed in river water at about 68°F (20°C) [*7*]. The principal contribution of the forensic science cases in our report is the knowledge of the precise temperatures to which the bodies were exposed during their five-year immersion period (Fig. 1). The water temperature was at or above 70°F (21°C) only about one month of each year (middle of July to middle of August) and was at or below "refrigerator temperature" (40°F, [4.4°C]) about six months of every year. Tomita observes that *C. perfringens* does not grow in laboratory conditions below 70°F (21°C), but its produced enzymes are active at much lower temperatures [*3*]. He also found it impossible to generate adipocere formation in a germ-free environment [*3*]. The bodies in our forensic science case reported here entered the water at the only time of year when the water temperature at that location is above 70°F (21°C). The subsequent drop in temperature within two to three weeks may well have arrested bacterial proliferation (assisted by the low pH induced by fatty acid liberation), although the bacterial produced enzymes may have permitted adipocere formation even at the reduced temperature after bacterial growth ceased [*3*]. Whether adipocere formation was completed during the initial month or two or whether this process was repeated each year when the temperature rose sufficiently to support further bacterial growth is purely speculative at this time. Knowledge of exact water temperatures to which the bodies were exposed permit reconstruction of a postulated sequence of events leading to tissue preservation by adipocere formation consistent with the observations of Tomita et al.

Conclusion

Based on the above, we believe it is reasonable to postulate that adipocere formed very rapidly in the bodies reported above. The warm water temperature, probably exceeding 70°F (21°C) at the time of immersion, facilitated the adipocere formation, preventing rapid skeletonization of the bodies and enabling them to be preserved in large part over the following five years. It seems likely that this change may not have occurred as completely if immersion had occurred at a time of the year when the water temperature was lower.

It is apparent that the presence of large amounts of adipocere is compatible with long submersion. Furthermore, the presence of large amounts of adipocere increases the likelihood that time of death and submersion occurred when the water was warm enough to permit bacterial growth. This information may be helpful in estimating the time of death in climates where temperature changes are quite dramatic.

Acknowledgments

We are indebted to G. B. Ostroski of Minnesota Power for his assistance and cooperation in providing the power company's temperature records.

We wish to thank the United States Coast Guard; Duluth Group, for safe transportation to the site when "thin ice" conditions would not allow us otherwise to measure temperatures safely.

References

[1] Evans, W. E. D., *The Chemistry of Death,* Charles C Thomas, Springfield, IL, 1963, p. 40.

[2] Mant, A. K. and Furbank, R., "Adipocere—A Review," *Journal of Forensic Medicine,* Vol. 4, No. 1, 1957, pp. 18-35.

[3] Tomita, K., "On the Production of Hydroxy Fatty Acids and Fatty Acid Oligomers in the Course of Adipocere Formation," *Japan Journal of Legal Medicine,* Vol. 38, No. 3, 1984, pp. 257-272.

[4] Takatori, T. and Yamaoka, A., "The Mechanisms of Adipocere Formation 1. Identification and Chemical Properties of Hydroxy Fatty Acids in Adipocere," *Forensic Science,* Vol. 9, 1977, pp. 63-73.

[5] Reh, H., Haarhoff, K., and Vogt, C. D., "Die Schatzung der Todeszeit bei Wasserleichen," *Zeitschrift für Rechtsmedizin,* Vol. 79, 1977, pp. 261-266.

[6] Takatori, T., Terazawa, K., Nakano, K., and Matsumiya, H., "Identification of 10-Hydroxy-12-Octadecenoic Acid in Adipocere," *Forensic Science International,* Vol. 23, 1983, pp. 117-122.

[7] Jobba, G. and Foldes, V., "Fruhzeitige Leichenwachsbildung," *Archiv Für Kriminologie,* Vol. 161, 1978, pp. 82-84.

[8] Mueller, B., *Gerichtliche Medizin,* Springer, Berlin, 1953, p. 59.

[9] Prokop, O., *Lehrbuch der gerichtliche medizin,* Volk und Gesundheit, Berlin, 1960, p. 61.

[10] Simonsen, J., "Early Formation in Adipocere in Temperature Climate," *Medicine, Science and the Law,* Vol. 17, 1977, p. 53.

Address requests for reprints or additional information to
G. E. Cotton, M.D., F.A.C.P.
UMD School of Medicine
10 University Dr.
Duluth, MN 55812