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Decomposition of Buried Human Bodies and Associated Death Scene Materials on Coral Atolls in the Tropical Pacific

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ABSTRACT: The decomposition of bodies and the decay of associated cultural materials, including clothing, personal ornaments, caskets, and grave goods, was investigated based on a series of exhumations on a small sand island on Kwajalein Atoll, Marshall Islands. Decay data were documented for an interment period between 40 and 80 months.

KEYWORDS: physical anthropology, decomposition, death scene materials, coral atolls, tropics

One interment, placed in a casket wrapped with plastic sheeting, thus effectively preventing the access of rainwater, had a marked development of adipocere with much of the muscle tissue still in a state of caseic fermentation at 80 months. Other interments showed that body tissue in a state of caseic fermentation can survive up to 70 months. Semi-closed spaces (trouser legs) delayed the decomposition. Ligaments survived well, some retaining adhesion to bone up to 60 months in open conditions, and up to 80 months in closed, water impermeable caskets. Hair was well preserved up to 80 months, while at 40 months skin had already decomposed and body parts with little tissue adhering (hands/feet) had skeletonized completely.

Organic cultural materials, such as *Pandanus* mats and items made of cotton showed evidence of partial or total decomposition. Synthetic or synthetic/cotton mix fibres, *en vogue* in the tropical Pacific, showed a remarkable state of preservation and are likely to survive as identifiable and traceable associated death scene material for quite some time. Polyester-cotton fabric was still well preserved after 80 months interment.

In the forensic context, the assessment of decomposition of human bodies is of importance to determine the time since death and to draw conclusions on the time and conditions of the disposal of a body. While there are considerable data on surface bodies and bodies interred in temperate climates, there is little known on the decomposition of bodies in the tropics. Likewise, analysis of the state of preservation and the survival of cultural material associated with death scenes is of considerable interest, but data derived from tropical environments are hard to come by.

In January 1993 the authors carried out a series of exhumations on Mejatto Island, Kwajalein Atoll, Republic of the Marshall Islands, which provide preliminary data on the matter.

Decomposition of Human Bodies—An Overview

The body of published literature on forensic medicine contains a number of studies related to assessing the time after death using the state of preservation of the body. Some data have been derived from case observations of human bodies [*1–6*], but most gained from comparative observations of animal cadavers such as rats [*8*], pigs [*9–13*] dogs [*3,14*] and deer [*15*]. A substantial number of studies look into the sequence of insect invasion of cadavers left on the surface, and attempts to arrive at estimates of the time since death [*1,3,9–12,16–23*]. Another, more limited body of literature is concerned with the bacterial changes a corpse undergoes after disposal [*24,25*], or the enzymatic destruction of the tissue and the bones [*26*]. In the regional perspective, the overwhelming number of studies have been conducted in temperature climates of the U.S.A. [*1,3–5,8–15*], Japan [*27*], and Europe [*2,28*]. Studies from Australia [*29*], New Zealand and South Africa [*30*] as well as assessments from tropical regions are rare [*31*]. Studies from the Pacific are virtually absent with the exception of Hawai'i [*16–21,23*], a single anecdotal evidence from Tonga [*32*] and data on eroding World War II burials in the Marshall Islands [*33*].

Based on a series of surface body decomposition studies conducted in Tennessee, Mann *et al.* [*1*] concluded that a number of variables affect bodily decay, and that all variables are important and interrelated. Based on a subjective five-point scale, Mann *et al.* rated (among others) the variables of temperature, access by insects, as well as burial and its depth as the most important variables (scale of 5 each) with humidity (4) and rainfall (3) being also important. The placement of human bodies directly in the soil, in coffins, plastic bags, or wrapping them in plastic delays decomposition, as the overwhelming majority of soft-tissue destruction is due to feeding by insect larvae. Burial of bodies restricts[3] or eliminates access of most species of carrion insects and also exposes the body to a reduced set of temperatures, both of which slow down the decomposition process [*1,5,7,35*]. Based on 160 exhumations after World War II Morovic-Budak [*2*] found that bodies buried in summer show a greater rate of decomposition

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[3] Some flies and carrion insects may be present in buried remains having hatched from eggs laid in the mortuary, the coffin, or from the surface of the earth [*5,34*].

than bodies buried in winter, which is most likely due to increased insect activity and higher temperatures.

Decomposition of Human Bodies in the Tropics

In the tropics three of the variables identified as causal are ever present: high temperatures, a high level of humidity and rainfall, usually at a high level. In principle, warm environmental temperatures improve the conditions for bacterial growth and thus hasten the putrefaction of the tissues. Cooler temperatures in turn retard bacterial growth and hence body decay.

Real observation data, however are limited. The decomposition of human surface bodies has been studied in detail in Hawai'i [*16–21,23*]. DeSaram [*31*] asserted for tropical Sri Lanka that putrefaction may set in 24 hours after death, leading to a swelling of the whole body by 60–72 hours. Bodies exposed to direct sun and outdoor heat "may so rapidly decompose within a 24 to 48 hour period as to make visual identification impossible" [*35*]. Limited data exist on fallen U.S. soldiers buried and later exhumed by Vietnamese authorities and surrendered to the U.S. [*36,37*]. The 23 individuals described in that study had been interred in a wet soil between 14 and 96 months. All remains had been limited to bones with no tissue adhering. Those remains interred for more than 20 months showed at least some evidence of bone erosion.

Colley and Spennemann [*38*] describe methods for preparing fish skeletons in the tropics, using putrefaction and maggots (insect invasion) to prepare clean fish skeletons. It took between 10 and 20 days to have fish skeletons completely cleaned. If the fish cadavers came into contact with the soil the skeletonization process was retarded but not stopped.

Decomposition of Human Bodies on Atolls

The islets making up the atolls are different from 'normal' tropical land and island environments in that they are smaller, have less fertile topsoil cover of a very sandy nature, and have limited rainfall and hence less luxuriant vegetation. Further, the non-marine fauna is very impoverished, with few arthropods reliant on flesh as a means to feed their offspring.

For the atolls of the Marshall Islands there are only a handful of data available, namely data gleaned from a World War II and post-World War II cemetery on Majuro Island ("Laura"), Majuro Atoll, from eroding cemeteries in the D-U-D area, also on Majuro Atoll, and World War II burials on various atolls. Given their location close to the shore, and given the relative instability of the shorelines of the islands making up an atoll, eroding cemeteries are a common occurrence in the Marshall Islands [*39*] and isolated human bones are often found in the inter-tidal zone and eroding on the islands surface [*40–51*]. In all cases, the bones were well macerated, free from fatty acids and slightly eroded at the compacta surface. None of these data are recent enough to be of good use for forensic scientists.

In addition, data can be obtained from the study of wartime photographs of U.S., Australian and Japanese corpses. Pacific Island battles during World War II resulted in a great number of casualties. Often it was not possible to bury the dead in a timely manner, and the photographic documentation available provides some insights into the decomposition process. Unfortunately none of these data seem to have been published in the accounts of the medical and pathological activities of the combatants in World War II.[4] A detailed assessment of the pictorial evidence is planned.

Deterioration of Associated Death Scene Materials

Buried death scene material has been the focus of some studies in the U.S. [*52,53*]. Morse and Dailey [*53*] analyzed the preservation of various clothing fibres in an experimental plot in Florida and showed that some materials, such as Rayon and cotton had life expectancies of 10 months or less, while Cotton/Polyester mixes survived with moderate damage up to 25 months and with severe damage up to 60 months. Nylon, on the other hand, showed no damage after 60 months, except in one instance. Nothing appears to be known, however, about the survival of death scene material in tropical environments, except that this environment is commonly regarded as the most destructive.

Purpose of the Mejatto Exhumations

Between 1946 and 1958 the United States of America detonated over 60 nuclear and thermonuclear devices in the northern Marshall Islands. In March 1954, a thermonuclear device yielding 15 million tons of TNT was detonated on Bikini Atoll as test *Bravo*. The radio-active cloud drifted eastward and contaminated numerous atolls, mainly Rongelap, Rongerik, and Uterik. The fallout following *Bravo* led to a significant deposition of plutonium and other transuranics, mainly ^{239}Pu, ^{240}Pu and ^{241}Am on the islands of Rongelap Atoll. Soil concentrations on Rongelap Island, Rongelap Atoll, are approximately a factor of 430 above the average of the northern hemisphere [*54*].

For many years conflicting information was available about the extent of transuranic uptake by the Rongelap community. Whereas dose estimates based on pathway modeling (uptake from estimated food intake, etc.) indicated that plutonium and other transuranics were only minor contributors to the overall dose, data on plutonium in urine collected before 1988 showed elevated levels of plutonium. While these data are unreliable due to potential contamination of urine samples with soil and problems with the analytical procedure, recent analyses of Brookhaven National Laboratories of urine from former Rongelap residents indicate low levels of plutonium uptake. Since about 45% of the initial uptake of plutonium into the bloodstream is deposited in the skeleton, with a biological half-life of 100 years, the analysis of actual bone samples for their total transuranic content reduces uncertainties associated with other data sources [*55*]. To provide independent verification of the estimates of plutonium intake via pathway modeling a series of six exhuma-

[4] Surveyed were the volumes of the following publication series (all held by the Australian War Memorial, Canberra): *Australia in the War of 1939–1945, Series 5 (Medical)*, Canberra, Australian War Memorial (several volumes) • *Official History of the Indian Armed Forces in the Second World War 1939–1945, Medical Services.* Combined Interservices Historical Section, India and Pakistan (several volumes) • *Official History of New Zealand in the Second World War 1939–1945 (Medicine)*, War Historical Branch, Department of Internal Affairs, Wellington, New Zealand (several volumes) • *History of the Second World War, United Kingdom Medical Services.* London, Her Majesty's Stationery Office (several volumes) • *Department of the Air Force, Medical Support of the Army Air Forces in World War II*, Office of the Surgeon General, U.S. Air Force, Washington D.C. (1955) • *Medical Department of the U.S. Army*, Office of the Surgeon General, U.S. Army, Washington, D.C. (several volumes). In addition, a few volumes exist on the events of World War I, such as the *Official History of the Australian Army Medical Services in the War of 1914–1918*, Australian War Memorial, Melbourne.

tions was carried out by the authors as part of a U.S. Congress funded study [*56*].

While the primary purpose of the exhumations as defined by the Rongelap Scientific Management Team was to recover sufficient bone tissue to conduct studies on the plutonium intake of individuals living on Rongelap Atoll after the *Bravo* thermonuclear test of 1954, they provided a unique opportunity to assess the decay rate of human bodies in the coral sand soils of the Marshall Islands [*57*]. In total seven individuals were to be exhumed, who had been interred for 40 to 80 months. In addition to the body samples to be collected (tibiae and femora), soil samples had to be taken above the burial, and if the casket had collapsed, both next to the bone samples and below the body to assess the effect of sample contamination by plutonium particles in the soil, if any.

Materials and Methods

Limitations of the Data Set

It was clear from the start, given the recent traumatic history of the Rongelap people in general and those now living on Mejatto in particular [*58,59*], that the exhumations would represent a very serious intrusion into their lives. Therefore, the exhumations had to be conducted as swiftly as possible. It was also clear that the exhumations would need to be a one-time event, and that one could not return to collect more body samples from the same or other individuals at a later date.

Even though the academic interest would have desired a much more detailed and thorough investigation of the state of decomposition of the bodies and the state of preservation of the burial goods encountered inside and outside of the caskets, this was deemed inappropriate. The exhumations had to be conducted in order to collect human bone samples for the assay of the plutonium content in the bones. All other observations were ancillary.

Since the exhumations represented a severe intrusion into the spiritual well-being of the community of Mejatto because the disturbance of human burials for any reasons was deemed inappropriate, the principles of minimal intrusion and appropriateness of the measures taken was espoused. This meant that the caskets were opened quickly, the state of the body documented photographically without disturbance of the interment, and that the bone samples were collected in a swift manner, so that the casket could be closed and the grave be reconsecrated.

Interment History

The bodies of individuals #1 to #3 and #5 and #6 were laid for one night for the customary wake period (*ilumij*), then placed in a home-made plywood coffin and buried the next morning (Table 1). During this period, even though continuously fanned away, flies may have had sufficient access to the body to start insect invasion (unknown). Interment #4 was different, however. The individual had protracted fish poisoning (Ciguetera) on Mejatto Island, and was eventually flown out to Honolulu, where he died. The body was placed in a casket and flown back to Kwajalein. From there it was brought by boat to Mejatto, where the body was laid up for one night for the customary wake period (*ilumij*).

Environmental Conditions

The Marshall Islands consist of atolls and raised islands aligned along two chains, Ralik and Ratak. Kwajalein Atoll, located in the Ralik Chain at 9°00′ North and 166°05′ East, comprises of 93 islets with a combined land area of 16.39 km,^{2} which makes it the largest discrete land area in the Marshall Islands. The atoll encloses a lagoon area of 2173.78 km,^{2} which is the largest atoll in the world. Kwajalein Atoll is a triangular atoll defined by the islands of Ebadon, Roi-Namur and Kwajalein as its western, northern and southern corners.

Climate—For the total lack of physical elevation and hence orographic rainfall patterns, the precipitation in the Marshall Islands is solely governed by the general Pacific-wide climatic belts. The long-term (1945–76) average annual precipitation of Kwajalein Island is 254 mm with a minimum of 178 mm (in 1965) and a maximum of 379 mm (in 1950). Precipitation is less during the months December to April, with February on average the driest month (~75 mm).

The temperature data show very little variation both in the long- and medium-term daily, monthly and annual temperature averages. In the long-term average (1959–1988), mean annual temperature was 27.3°C (81.1°F), with an average maximum of 27.5°C (81.6°F) and an average minimum of 26.6°C (80.0°F). The annual daily maxima and mini-ma are marginally more pronounced, with a night-time minimum in the low 20s and a day-time maximum in the mid-30s. Relative humidity averages between 75% and 85% over the year with little annual variation. Humidity approaches 100% during and after intense rainstorms (squalls) [*60,61*].

Soils—The islands on the reef platform of individual atolls can be geomorphologically grouped into those that are located on the windward side and those that are on the leeward side of the atoll. The ocean ward reef flat of the leeward islands, such as Mejatto, is commonly relatively wide and covered with homogeneously cemented beachrock deposits, which were formed in response of the reasonably sheltered conditions with little pounding of wind driven waves and long ocean swell. The leeward islands commonly show only a small boulder rampart with little if any boulders strewn across the ocean reef flat. The islands are made up of fine

TABLE 1—*Details of the exhumed of individuals on Mejatto.*

Exhumation	Sex	Age at death (years)	Cause of death	Time since death (months)	Place of death	Type of casket
Individual #1	F	38	Hemorrhage at child birth	80	Mejatto	Plywood
Individual #2	M	77	Unknown	70	Mejatto	Plywood
Individual #3	M	33	'Heart problem'	58	Mejatto	Plywood
Individual #4	M	33	Fish poisoning	41	Honolulu	Cardboard w plywood
Individual #5	F	10	Unknown	79	Mejatto	Plywood
Individual #6	F	9	Acute appendicitis	71	Mejatto	Plywood w plastic

to coarse grained sand, with only little gravel in the central portions. The interior of the larger islands is commonly characterized by slightly loamy sands with dark surfaces, indicative of an increased humus content in the soil derived from decayed vegetation. The characteristics of the Mejatto Island soils in the vicinity of the exhumations are set out in Table 2 [*62,63*].

Vegetation—The vegetation of Mejatto Island no longer exhibits a systematic zonation. This is caused by the activities of the Rongelap people, cutting the vegetation for settlement extension and firewood purposes, and by the artificial planting of other vegetation. The majority of Mejatto is covered by low shrubland, with much exposed coral sand, and interspersed coconut palms [*63,64*].

The Exhumation Procedure

After considering the constraints of one-time exhumation etc., the following procedure was adopted.

Site clearance—The graves to be exhumed were identified and the area was cleared of all vegetation. It is custom in the Marshall Islands that cemeteries are left to go to seed until a new interment is about to take place. Then the *entire* cemetery is cleared of all vegetation but the trees and very large bushes. At the same time, the graves, usually all graves of the cemetery if it is not too large, are repainted and new coral gravel is applied [*67*].

The coral gravel coverage inside of and surrounding the grave markers of exhumations was removed and piled up at the location off the intended locations for the spoil heaps, so that the coral could be re-used at a later point in time. In addition, care was taken to avoid unnecessary (unsightly) contamination of the coral gravel with excavated soil. The amount of intrusion into the physical appearance of the cemetery was kept to the absolute minimum so that rehabilitation of the cemetery would be easy.

Exhumations

Each of the six exhumations were to be conducted according to a set pattern of eight phases. The average interment depth was said to be six to seven feet according to the local informants asked. In order to keep tight control over the stratigraphy and any intrusions, the exhumation was to be executed in four artificial spits. Based on the average depth of 1.8 m ('six feet') the thickness of the spits was set to be 0.4 m. The bottom of each spit ('planum') was to be cleared in a level fashion to determine variation of soil colour and consistency

Phase 1 Gridding of the grave, excavation and documentation of planum 1.
Phase 2 Excavation and documentation of planum 2.
Phase 3 Excavation and documentation of planum 3.
Phase 4 Excavation and documentation of planum 4 (estimated to be on the body.)
Phase 5 Collection of soil sample above body, documentation of interment.
Phase 6 Collection of human body samples and of soil samples underneath the body.
Phase 7 Documentation of the profiles of the excavation pit and of the grave goods (if any).
Phase 8 Reconsecration of the grave and refill of the grave pit.

The reality of the fieldwork, however, dictated a different system. The graves turned out to be 1.2 to 1.5 m deep (to the top of the casket), and the fill too unconsolidated to allow for more frequent plana within the limited time frame given. In the final pattern, planum 1 was set at two feet (0.6 m) and planum 2 at 1.0 or 1.2 m. Planum 3 was set just above the casket, often with the casket perimeter showing. At this level the soil samples would be taken. Planum 4 was taken to be the exposed and opened casket.

Documentation

Prior to the exhumations the lay-out of the cemetery was mapped and recorded. The graves to be exhumed were identified and marked on the map. During the exhumation process a systematic documentation was maintained, consisting of

• written documentation in a prepared separate notebook for each exhumation;

TABLE 2—*Characteristics of the soils encountered at Mejatto.*

Soil	Type	Consistency	Colour [*65,66*]	Percolation rate
#1	Subangular coarse, very loose sand	Single grain, non-sticky and non-plastic. This soil has no humus content and no root matter	Very pale brown to pinkish white/ pinkish gray color (Munsell 7.5–10YR 7–8/2-3).	37.7 liters/sqm and minute
#2	Subangular medium to coarse, very loose sand	Single grain, non-sticky and non-plastic. This soil has some root matter.	Light brownish gray color (Munsell 2.5Y6/2).	not determined
#3	Subangular mainly medium, partially coarse, sand	Single grain, friable, non-sticky and non-plastic. This soil has a very small humus content and a higher content of root matter than soils #1 or #2.	Dark gray to dark grayish brown color (Munsell 2.5Y 4/ 1–2).	154 liters/sqm and minute
#4	Subangular mainly medium, partially coarse, sand	Single grain, friable, non-sticky and non-plastic. This soil has a very small humus content and a higher content of root matter than soils #1 or #2.	Gray to grayish brown color (Munsell 2.5Y 6/1–2).	Not determined

• audio documentation, where findings were dictated on a small hand-held tape recorder (and later entered in the notebook); and
• visual documentation, where each individual step of the exhumation process was photographed and the profiles, as well as plana were drawn to scale (into the notebook).

Each phase of the exhumation was documented in detail. Documented were the location of the interment in relation to island and the description of the grave site prior to exhumation, including the discussion and description of the grave marker and its material. The exhumation was described in terms of weather conditions during the exhumation, site clearing, excavations, sampling, and recovery of human material for analysis. The description of interment included the position of body, and the orientation of body; the description of the stratigraphies of plana and the western, southern, eastern and northern profiles; the description of the burial pit—its size, depth, shape and animal disturbances if any; the description of the grave accessories, such as the casket and its components, any grave goods encountered, both inside and outside of the casket, such as personal belongings, items of clothing, jewelry, medical and embalmer's items and their spatial distribution in relation to the anatomical remains. The observed decomposition patterns were described in terms of the overall state of decomposition; that of the types (skin, hair, nails, flesh, tendons, cartilage, teeth, bones) and that of the anatomical groups, namely head-neck area, shoulder girdle and upper arms, lower arms, hands, spine, hip girdle and upper legs, lower legs, and feet. Finally, the movement of anatomical elements within the grave pit is addressed.

Results

The six exhumations provided the following data on the decomposition of human remains and the decay of cultural materials associated with the graves. The bodies had been placed in locally-made wooden caskets made of plywood, except for one, which was buried in an imported casket of cardboard-like material. At the time of exhumation all caskets but the latter were still intact, albeit in various stages of near-collapse. These caskets thus provided for a humid air space in which decomposition could occur.

Decomposition of Human Remains

Before the exhumations it had been expected that individual #4, a person who had died in Hawai'i, would be substantially less decomposed than all others. It was suspected that this body had been (partially) embalmed. The reality, however, was that this body was fully skeletonized.

Adipocere formation has been frequently described in the literature [*24,26,65*]. Among the six exhumed individuals only one, #5, showed what appears to be strong adipocere formation (Fig. 1). The face and neck of #5 was covered with adipocere, with the right eyeball distinctively visible. When the body was touched to access the left humerus through the neck of the dress, the head was moved backwards and the vertebral column snapped with an audible cracking sound. The shoulder girdle seems to have remained intact with most of the flesh still adhering to the bones. The flesh had turned into a cheeselike, crumbly substance. The humeri could be separated from the scapulae without any major problems and extracted. The epiphyses had already separated from the diaphyses. The chest had partially collapsed but was still filled with a caseic material and the dress seemed still to be in a tight fit around the body. No inspection of the central body cavity was carried out. The pelvic and the femuro-tibial joints could be separated by pulling without much problem. A great amount of caseic flesh was found adhering to them but could be shaken off easily. The epiphyses had already separated from the diaphyses. The feet had not yet skeletonized and adipocere formation was observed.

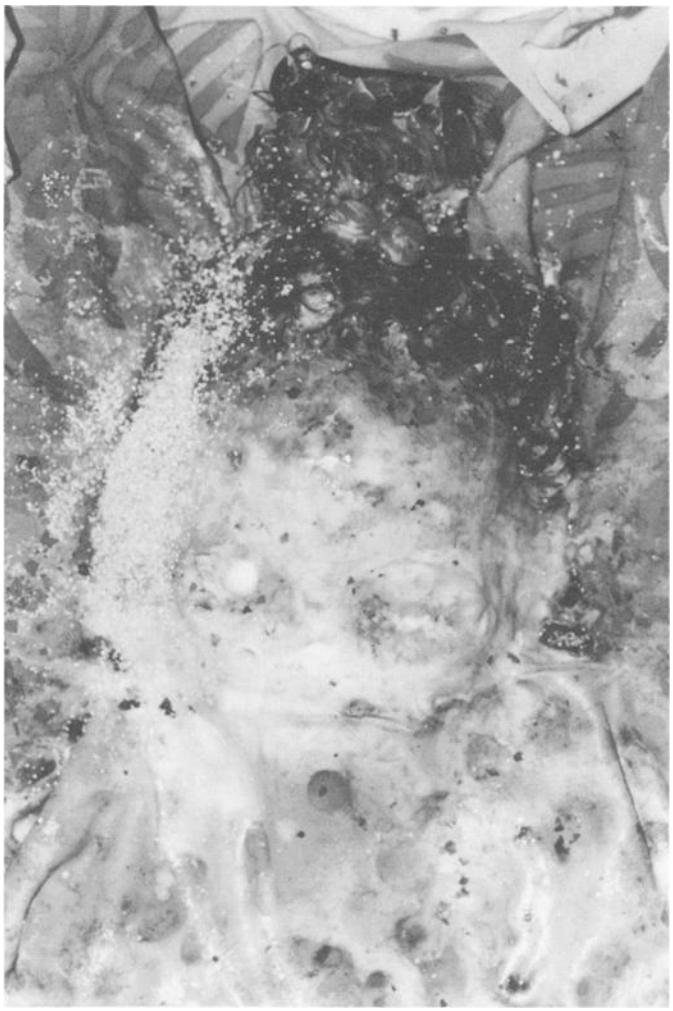

FIG. 1—*Adipocere formation of individual #5.*

With the exception of interment #5, the exhumed bodies were in advanced stages of skeletonization (Table 3 for details). Head-neck areas, chests, spinal columns (upper) hands and feet showed complete skeletonization. For example, the proximal epiphyses of the femora of #6 fell off when the femora were pulled out and were not recovered as samples. The hip and knee showed some variation, with three (#1, #2, #6) completely skeletonized and two (#3, #4) with varying amounts of amount of white (#3) or brown #4), caseic tissue attached to it, as well as many ligaments. The caseic tissue could be shaken off easily, while the ligaments in one case (#3) remained attached and were collected as part of the sample.

No skin could be observed at the hand, foot and leg areas which were exposed during the exhumations (refer to Table 3 for details). Hair was observed in interments #1, #2, #5 and #6, and did not appear to have lost its black color (#5, #6). It is unknown whether they were still attached to the skull or not. None of the exhumations were systematically searched for nail remains.

TABLE 3—*State of decomposition of the interments at Mejatto by anatomical group and type of body tissue.*

Individual	1	2	3	4	5	6
TSD (months)	80	70	58	41	79	71
Anatomical group						
Head-Neck	?	Skeletonized, mandible detached	?	?	Head covered in adipocere, head-neck articulated, separated when moved, black-colored hair mass present	Completely skeletonized, black-colored hair mass present
Neck	V. cervicales skeletonized ?	V. cervicales skeletonized	?	?	V. cervicales connected	V. cervicales skeletonized
Shoulder area	?	?	?	?	Mascerated, flesh in caseic fermentation	Skeletonized
Upper arms	Skeletonized	?	?	?	Mascerated, caseic tissue present, epiphyses separated	Skeletonized, distal epiphyses separated
Lower arms	?	?	?	?	?	?
Hands	Skeletonized	?	?	?	?	?
Chest	Collapsed	Collapsed	Collapsed and skeletonized	Collapsed	Adipocere, shape preserved	Collapsed
Abdomen	Disintegrated	Disintegrated	Disintegrated	Disintegrated	Adipocere, shape preserved	Disintegrated
Spine	Skeletonized	Skeletonized?	?	?	Adipocere, intact ?	?
Hip joints	Skeletonized	Skeletonized	Mascerated, caseic tissue present, ligaments adhering	Mascerated, caseic tissue present, ligaments adhering	Mascerated, caseic tissue present, ligaments adhering, epiphyses separated	Mascerated, small amounts of caseic tissue present
Upper legs	Skeletonized	Skeletonized	Mascerated, caseic tissue present on both femora, more on right	Mascerated, caseic tissue present only on right femur	Adipocere, shape preserved, femora mascerated, caseic tissue present on both femora, epiphyses separated	Mascerated, proximal epiphyses separated, small amounts of caseic tissue present on both femora
Lower legs	Patella and tibia skeletonized	Patella and tibia skeletonized	Patella skeletonized, tibia mascerated, caseic tissue present	Patella skeletonized, tibia mascerated, caseic tissue present, ligaments adhering	Patella skeletonized, tibia mascerated, caseic tissue present on both tibiae, epiphyses separated	Patella and tibia skeletonized
Feet	Skeletonized	Skeletonized	Skeletonized?	Skeletonized and separated	Adipocere, shape preserved	Skeletonized
Tissue type						
Skin	Fully decomposed	Fully decomposed	Fully decomposed	Fully decomposed	Fully decomposed	Fully decomposed
Hair	Good	Good	?	?	Good	Good
Nails	?	?	?	?	?	?
Flesh	Fully decomposed	Fully decomposed	Caseic	Caseic	Caseic	Caseic
Tendons	Fully decomposed	Fully decomposed	Good	Good	Fair	Fully decomposed
Cartillage	Fully decomposed	Fully decomposed	Fully decomposed	Fully decomposed	Fully decomposed(?)	Fully decomposed
Teeth	Good	Good	?	?	?	Postmortem loss
Bones	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Adipocere	...	...	...	...	Good	...

Three of the interments (#3, #4, #6) showed remains of flesh in a state of caseic fermentation at the femora (see Table 3). The muscle tissue of the femora as well as the proximal ends of the tibiae of #3 (most prominent on the right leg) had a white, cheese-like, crumbly appearance (caseic fermentation completed), which could easily be shaken off. In #4, large chunks of a dark brown colored cheeselike mass (caseic fermentation of body tissue) could be observed only on the right femur. The entire body of #5, including the face and the feet, seems to have flesh remains adhering to them. The flesh, where touched or removed to access the bones

collected for sampling, had a cheeselike, crumbly appearance. When the bones were pulled out, the interior of the white caseic mass showed evidence of reddish-purple streaking in the pattern reminiscent of muscle ligaments and fibers. The right eyeball was still prominently visible, although covered with adipocere.

Some ligaments of the proximal end of the right tibia of #4 and the right hip joint of #3 had survived, the latter were still firmly attached to the *caput femoris* when the femur was pulled out.

The bones recovered for sampling made a fresh and "greasy" appearance, with probably some, if not most, of the body fats in the marrow cavity still present. The epiphyses of #6 separated easily from the diaphyses. The femuro-tibial joint of #2 showed evidence of very severe osteoarthritis with the development of narrow and well defined growth ridges. None of these growth areas showed erosion of the bone tissue.

Deterioration of Associated Death Scene Materials

Deterioration of Items of Clothing—The body of #1 had been covered with a shroud. Only the leg end of the sheet was lifted to extract the bone samples. The woman was wearing a white (?) dress and a petticoat, both of synthetic materials. The fabric of both was in a good state of preservation. When the entire cloth mass was lifted off the bottom of the casket of #1, to assess whether it would be feasible to collect a soil sample from underneath the casket, a large patch of green to blue-green fungus was seen between the cloth and the plywood (Table 4).

The body of #2 was dressed in a pair of tightly woven, jeanslike light brown trousers, which was intact, firm and strong of material, and of overall good condition. (The upper part of the body was not disturbed).

A pair of track suit trousers, made of a synthetic material, was encountered outside the casket lying on top of the southern foot end of the coffin of #3. The trousers were colored black, red and yellow. None of the dyes had given off any color pigments to the surrounding soil. The fabric was firm.

The preservation of the suit of #4 was good. No deterioration of the cloth material could be observed from macroscopic observation.

The legs of the jeanslike trousers of #3, made of a cotton material (?), tore at the seams when the shroud was partially removed (slipped up). The socks had partially disintegrated around the hems, but otherwise consisted of synthetic material, which was still strong and intact. They contained the disarticulated foot remains. It appears that the hems had disintegrated, which had elastic rubber band covered with cotton woven into them.

A pair of black colored slip-on shoes, of a synthetic upper material and a yellow rubber or plastic sole was found to be very well preserved.

The clothing items of #6 were in a good state of preservation.

Deterioration of Other Fabric—An aluminum bucket had been placed on the foot end of the casket of #1. The bucket, which had a diameter of 340 mm, was sown into a green and white-striped cloth. The cloth covering the bucket was of a polyester-mix fabric, and in very good and strong condition (Table 5).

Two black frilly bands were placed on the chest, and a garland of pink synthetic flowers was placed on the waist of #1. Both appeared to be in excellent condition. A similar band was seen in the casket of #4, also of good condition.

The inside bottom and sides of casket #3 had been covered with an orange colored print that had green and blue flower motifs on it. The colors of the print were still bright.

TABLE 4—*State of deterioration of clothing and personal ornaments of the interments at Mejatto.*

Individual	Material	1	2	3	4	5	6
Sex		Female	Male	Male	Male	Female	Female
Age at death (years)		38	77	33	33	10	9
TSD (months)		80	70	58	41	79	71
Black band	Polyester	Excellent (2×)	...	...	Excellent	...	...
Bows (bands)	Synthetic	...	...	...	...	...	Very good (2×)
Buttons	Hard plastic	...	...	...	Excellent	Excellent	Excellent
Dress	Synthetics	Very good	...	...	...	Good	Good
Hair claps	Hard plastic/metal	...	...	...	...	Very good	Very good (5×)
Mattress(?)	Unknown	...	...	...	...	Good (?)	...
Necklace	Hard plastic	...	...	...	...	...	Excellent (3×)
Ornamental band	Synthetic	...	...	...	...	...	Excellent
Petticoat	Synthetics	Very good	...	...	...	...	...
Pillow (fill)	Foam (?)	Good	Good	Good	Good	Good	Good
Pillow case	Polyester/cotton	Good	Good	Good	Good	Good	Good
Plastic flowers	Hard plastic	...	Excellent	...	...	...	Excellent
Pottery sherd	Bone china	...	...	...	...	...	Excellent
Shoes (soles)	Soft plastic	...	...	Good	...	...	...
Shoes (top)	Synthetic leather	...	...	Good	...	...	...
Shopping bag	Soft plastic	...	...	...	Good	...	Good
Shroud	Polyester/cotton	Good	Good	Good	Good	Good	Good
Sleeping mat	*Pandanus*	...	Poor	Poor (2×)	...	...	...
Socks	Polyester/cotton	...	...	Fair	Good	...	...
Suit/Jacket	Polyester/cotton	...	...	...	Good	...	...
Trousers	Polyester/cotton	...	Good	Fair	Good	...	...
Zipper (trousers)	Metal or plastic	...	Unknown	Unknown	Unknown	...	...

NOTE: Definitions for state of preservation: *excellent*—no deterioration can be detected macroscopically; *very good*—no deterioration can be observed macroscopically, but material appears 'aged'; *good*—material is intact, not disintegrated, but shows evidence of structural weakening; *fair*—material shows evidence of disintegration, with parts of the fabric missing or disintegrating when moved; *poor*—much of the fabric is missing or disintegrating beyond recognition when moved; *gone*—fabric has completely disintegrated and its former presence can only be inferred (for example by the presence of buttons etc.).

TABLE 5—*State of deterioration of grave accessories of the interments at Mejatto.*

Individual	Material	1	2	3	4	5	6
Sex		Female	Male	Male	Male	Female	Female
Age at death (years)		38	77	33	33	10	9
TSD (months)		80	70	58	41	79	71
Bucket[a]	Aluminum	Very good	Very good	...	...	...	...
Clothes	Polyester/cotton	Good	...	...	...	...	...
Polaroid® photos		...	...	...	fair	...	...
Rope[b]	Hemp?	...	...	Fair	...	...	...
Shopping bag	Soft plastic	Fair	...	...	...	...	...
Sleeping mat	Synthetic	...	...	Good	...	...	...
Track suit trousers	Polyester (?)	...	...	Excellent	...	...	...

NOTES: [a] as container [b]unintentional grave good?.

A length of rope was encountered, partially tied around the casket of #3. The rope, made of hemp or Manila hemp had a diameter of about $^3/_8$ to $^1/_2$ inch. It was solid and very strong and needed to be cut with a knife for removal.

Deterioration of Caskets—All caskets but that of #4 were of similar construction. Thus the description of the casket of #1 may serve as an example (Table 6).

The casket, measuring 0.8 by 1.7 by 0.3 m in dimensions, was made of commercially available 12 mm ($^1/_2$ inch) untreated plywood, held together by small galvanized iron nails. The casket itself was covered with a cotton/polyester-mix fabric bed sheet, of brown-gray, formerly probably of white color. The sheet apparently had become stained by humic acid carried by rainwater from the higher levels of the stratigraphy. The insides of the coffin had been lined with a white bed sheet. The sides and the lid of the casket were held together with galvanized iron nails set at irregular intervals. The wood of the casket was in an advanced state of deterioration, although, on the whole, intact. The wood had become thoroughly soaked by the humidity of the soil and the glue seems to have come apart, making the plywood very flexible. The nails broke out very easily when the coffin was pried open with a hammer. The left (northern) side of the coffin had collapsed and bent inwards, causing the coffin lid to slump in that direction. The coffin afforded substantial air space even at this stage of deterioration.

Different was the casket for #4 that had come from Honolulu. The casket was made of a card-board or press paper-board like material, which crumbled upon impact. The thickness of the cardboard was about 25 mm (1 inch). The casket lid had two small plywood sections on the top (~0.3 to 0.5 m), apparently to strengthen it and to provide solid flat surfaces upon which other items could be placed during the burial ceremony. On the outside the casket was covered with a dark gray cloth material. On the inside, the casket had been lined with a white cloth. In the cross-section the casket was hexagonal rather than rectangular as were the home-made caskets. It had become soaked with humidity and the glue holding together the cardboard/press board seems to have become partially dissolved. At the time of the exhumation the sides of the lid of the casket had caved in. When it was attempted to removed the lid, it broke into a number of large chunks. The plywood parts of the lid had separated from the cloth cover. The plywood itself was in fair condition.

Like others, the casket of #5 was covered with a cotton/polyester-mix fabric, of brown-gray color. On top of this fabric a layer of transparent sheet plastic, commonly used as a building material, was placed. The plastic also covered the lid of the casket with an overhang on all sides, thus effectively sealing off the interior of the casket.

Deterioration of Woven Mats—Two interments (#2, #3) contained mats woven from leaves of the *Pandanus* tree. One (#4) contained a rolled-up sleeping mat of synthetic fibers outside the casket.

The body of #2 (buried for almost 6 years) had been placed on a *jaki* mat (sleeping mat) woven from *Pandanus*, which was partially wrapped around the body, leaving only the head and the center axis of the body free. The body was covered with a linen shroud, presumably a bed sheet, which was tucked under the mat ends. Mat and shroud were covered with a fine layer of black silt. The mat had turned dark brown and was very wet on touch. The weave pattern was well discernible. When the shroud was pulled up to

TABLE 6—*State of deterioration of the caskets of the interments at Mejatto.*

Individual	Material	1	2	3	4	5	6
Sex		Female	Male	Male	Male	Female	Female
Age at death (years)		38	77	33	33	10	9
TSD (months)		80	70	58	41	79	71
Cloth cover	Cotton	...	...	...	Poor	...	...
Cloth cover	Polyester/cotton	Good	Good	Good	...	Good	Good
Cloth lining	Cotton	...	...	...	Poor	...	...
Cloth lining	Polyester/cotton	Good	Good	Good	...	Good	Good
Nails	Galvanized iron	Very good	Very good	Very good	...	Very good	Very good
Ornament	Polyester web	...	...	...	...	Excellent	
Plastic lining	Soft clear plastic	...	...	...	...	Excellent	...
Plywood	12 mm ($^1/_2$")	Soft, fair	Soft, fair	Soft, fair	Soft, fair	Soft, fair	Soft good
Press board	Cardboard	...	...	...	Poor	...	...

expose the legs for the removal of the bone samples, the mat crumbled into small pieces. The deterioration of the mat seems to have been more pronounced at the foot end of the buried individual than at the head end.

The body of #3 (buried for almost 5 years) was covered with a mat folded length wise woven from *Pandanus* leaves (*jaki*). This mat partially covered the body as well and overlapped with the shroud. When the casket was opened, the mat was still intact, but crumbled to small unrecognizable pieces when the shroud was lifted and moved up to expose the lower legs. It had completely deteriorated and turned into a silty substance, which still maintained the weave pattern. The bottom of the casket had been covered with another mat, which had become completely deteriorated. In addition, a great amount of mold could be observed between the cloth of the trouser legs and the *Pandanus* mat.

A well preserved, modern type, Japanese-made *jaki* mat, woven from yellow-brown and green synthetic fibers was found folded and rolled up on top of the northern central section of the casket of #4.

Deterioration of Items of Plastic—A plastic shopping bag (supermarket-type bag) had been placed on foot end of the casket of 1. The plastic bag, which was scuffed and torn, but otherwise diagnostic, contained a piece of red colored clothing, which gave off some red dye, staining the sand in contact with the clothing.

An ornamented belt, made of a belt string with green and black plastic beads (diameter ~3–5 mm) attached in a spiral fashion was seen inside the casket of #1. The string was in what appeared to be perfect condition.

On top of the shroud of #6 a number of grave goods had been placed. On top of the stomach area a multiple bow ornament was placed, made of a golden, waxed paper band, with a blue flower in the center. A similar item of blue color was placed on the right chest. A long necklace of golden plastic beads (diameter approximately 8 mm) was spread over the stomach, and a necklace of light green plastic beads (diameter approximately 3 to 5 mm) was spread on the chest. A similar necklace, laid out parallel to the body, was placed between the legs. The preservation of all items, including the waxed paper band, was excellent.

The neck of the dress of #6 was buttoned tight, the plastic buttons being in good condition. The hair was held in place by five bowlike plastic hair clasps, two of transparent brown color, two opaque yellow and one of an opaque red. All items of plastic were in good condition with no trace of deterioration.

Deterioration of Metal Items—An aluminum bucket had been placed on the left foot end of the casket of #1. The bucket, which had a diameter of 340 mm, was sown into a green and white-striped cloth. Only the handle of the bucket protruded from the parcel. No deterioration of the aluminum was observed. An aluminum bucket, with an orifice of 340 mm, containing clothes (?) was placed at the foot end of the grave pit next to the casket of #2.

Deterioration of Photographs—Three Polaroid® photos were seen on top of the casket of #4. Two of them could be separated and were looked at. The emulsion had turned yellow and the shadowy outline of a man, possibly that of the deceased, can be made out. Sufficient detail for a proper recognition were possible.

Discussion

The decay of body tissues and cultural material could be documented for an interment period between 40 and 80 months. The bodies had been placed in locally made wooden caskets made of plywood, except for one, which was buried in an imported casket of cardboardlike material.

Five of the six exhumations had been made in water permeable caskets, while one casket (#5) had been wrapped with plastic sheeting, thus effectively preventing the access for percolating rainwater. That burial had a marked development of adipocere (Fig. 1) with much of the muscle tissue still in a state of caseic fermentation. The state of preservation of the body in that burial was much better than that of any of the others even though it represents the longest interment period (80 months). This observation is consistent with that of Mant and Fairbank [*69*], who mention that interments in loosely made coffins with large air spaces and which were permeable to water, showed no adipocere. The chronological assessment reveals that body tissue in a state of caseic fermentation can survive up to 70 months. It appears that semi-closed spaces, such as trouser legs facilitate the survival of caseic matter, or conversely, delay the decomposition. This observation is confirmed by Vanezis *et al.* [*7*] who found that decomposition of a corpse progresses at a slower rate where it is in contact with the earth or bottom of a coffin, or where clothing is tight, such as in trouser legs. Worth noting is the observed differential preservation of caseic matter in Mejatto #3 and #4, where in both cases the right leg had more or better preserved caseic matter attached than the left.

Ligaments were found to survive well and retain adhesion to the bone up to 60 months in open conditions, and up to 80 months in closed, water impermeable caskets. Hair matter was seen to be well preserved up to 80 months, while skin had already decomposed at 40 months. The chest cavity and abdomen had collapsed in all cases except where adipocere had formed, and body parts with little tissue adhering, such as hands and feet, seemed to have skeletonized completely.

No marked body movement had occurred within the caskets. Only in one case (#3) a movement was observed, with the feet pointing outwards, but a femur being twisted inwards, albeit slightly.

Organic cultural materials, such as *Pandanus* mats and items made of cotton showed evidence of partial or total decomposition, while synthetic fibers showed a remarkable state of preservation. Polyester-cotton fabric was still well preserved after 80 months interment. Since 'cheap' synthetic or synthetic/cotton mix fibers are *en vogue* in the tropical Pacific, this implies that associated death scene material is likely to survive as identifiable and traceable materials for quite some time. Traditional organic materials, however, decomposed very rapidly (Table 7).

How do the Mejatto data compare to other tropical areas? Only one tropical data set was available for comparison with the Mejatto data. The 23 individuals buried and later exhumed by Vietnamese authorities described in a study by Warren [*36,37*] had been interred between 14 and 96 months. All remains returned to U. S. authorities had been limited to bones with no tissue adhering, it being unclear whether the bones had been cleaned before turn over. Those remains interred for more than 20 months showed at least some evidence of bone erosion. Compared to that data set where the bodies had been interred in a wet soil without caskets or body bags, the Mejatto interments which were in caskets, show a markedly slower rate of decomposition. Morovic-Budak [*2*], in his Yugoslavia study found that among burials interred in summer, some residual tissue may be adhering by 48 months, but that by 72 months all bones had completely skeletonized. With the excep-

TABLE 7—*Decay of cultural materials at given durations of interment (in months).*

Material	Interment period (months)				
	40	50	60	70	80 (sealed)
Aluminum	...	Very good	...	Very good	Very good
Bone china	...	Excellent	...	Excellent	...
Cardboard	Poor	?	...	...	...
Cotton	Poor	?	...	...	...
Cotton thread	...	?	Poor	...	...
Cotton-covered rubber	...	?	Poor	...	...
Foam (?)	Good	Good	Good	Good	Good
Galvanized iron	...	?	Very good	Very good	Very good
Hard plastic	Excellent	Excellent	...	Excellent	Excellent
Hemp?	...	?	Fair	...	...
Brass	...	Very good	...	Very good	Very good
Pandanus	...	?	Poor (2×)	Poor	...
Plywood	Soft, fair	Soft, fair	Soft, fair	Soft, fair	Soft, fair
Polaroid® photos	Fair	...	...	...	...
Polyester	Excellent	Excellent	Excellent	...	Excellent
Polyester/cotton mix	Good	Good	Good	Good	Good
Soft plastic, thick	...	Good	Good	...	Good
Soft plastic, thin	Good	Good	Good	Good	Fair
Synthetic leather	...	?	Good	...	...
Synthetic, thick	...	Excellent	Excellent	Excellent	...
Synthetics, thin	...	Good	...	Good	Good

NOTE: The preservation status for 50 months has been interpolated.

tion of the adipocere case, this decomposition pattern is within the range of the Mejatto data.

Future Research Directions

The data set presented in this study, albeit anecdotal, is hitherto unique. As pointed out repeatedly, it is limited in numbers and chronological duration. Further data and systematic studies are required to provide tighter time lines on the decomposition of bodies and cultural material on coral sand islands. This is especially so for the interment period less than 40 months.

Several variables are likely to influence the rate of decomposition:

- the rate of water percolation (and hence particle transport) through the sandy soil, which is governed by the particle size of the sand and its humus content. Islands on the windward side of an atoll, for example, comprise, on the whole, of a more coarse grained sediment, that the larger, geomorphologically more stable islands on the leeward side.
- total amount of rainfall, which varies from almost 4000 mm in the south (Jaluit Atoll, 5°47′ N) to 1000 mm in the north (Eneen-Kio/Wake, 19°28′N).
- the level of ground water. Whilst most burials are set in dry ground, some very low-lying islands (max elevation 1 m above HWL) permit burial only at low tide (when the Ghyben-Herzberg ground water lens is lowered) and imply cyclic diurnal immersion of the body with water.

From a forensic point of view it would be very desirable to conduct similar observations in similar environments to add to the data presented here.

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