REPORTS

THE ARCHAEOLOGY OF CONTEMPORARY LANDFILLS

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The Garbage Project has excavated eight sanitary landfills from California to Florida and analyzed 6.71 metric tons of refuse deposited between 1952 and 1988. While the ultimate goal of this continuing endeavor is to collect archaeological data on contemporary discards using a methodology that will link our society to the past, this initial report relates Garbage Project data to three issues of current public concern. This first applied archaeology of landfills has identified: (1) the contents of specific landfills and possible refinements for "national" estimates of U.S. landfill contents; (2) a link between moisture level and rate of refuse decomposition; and (3) part of the pathway of migration for heavy metals.

El Proyecto Basura ha excavado ocho rellenos sanitarios localizados en sitios desde California hasta la Florida y ha analizado un total de 6.71 toneladas métricas de desechos depositados en un período que abarca desde 1952 a 1988. Nuestros trabajos de investigación tienen como meta primordial el recolectar datos arqueológicos de los desechos contemporáneos utilizando una metodología que vincula a nuestra sociedad con su pasado. Este informe inicial establece relaciones entre los datos sistemáticamente recolectados por el Proyecto Basura y tres temas actuales de creciente interés público. Este primer estudio de arqueología aplicada a los rellenos sanitarios ha identificado: (1) el contenido de rellenos sanitarios específicos, cuyos datos podrían refinarse para derivar estimaciones "nacionales" del contenido de los rellenos sanitarios en los Estados Unidos; (2) la estrecha relación entre los niveles de humedad en los depósitos de basura y el ritmo de la descomposición de los desechos; y (3) una parte crucial de los cauces de flujo de los metales pesados identificados como contaminantes del agua.

Current "garbage crisis" concerns over the quantity and potential toxicity of refuse are embedded in landfills. In the United States, these imposing mounds are the repositories for more than 70 percent of the municipal solid waste (MSW) generated today (Franklin Associates 1990). Even given Herculean efforts to implement recycling, incineration, and source reduction alternatives, the predominant role in solid-waste disposal in the near future will be played by landfills.

Landfills are important to archaeologists because we learn about past societies by excavating buried discards. In 1987, archaeologists from the Garbage Project (Rathje 1991; Rathje and Ritenbaugh 1984) began digging for garbage inside contemporary landfills. Research centered on modern landfills is nothing new. Studies have documented the solid wastes entering (Duxbury and Associates 1990; Rathje et al. 1987; Rathje, Wilson et al. 1989; Russell and Meiorin 1985; Savage and Sharpe 1987; SCS Engineers 1986; Wilson and Rathje 1989) and the leachates exiting landfills (Brown and Donnelly 1988; Dunlap et al. 1976; Sawhney and Kozioski 1984), and landfill design experiments have been conducted in labs (Bogner 1990; Bogner et al. 1989; Shelton and Tiedje 1984), in lysimeters (Barlaz et al. 1990; Kinman et al. 1985), and at test cells at landfills (Ham et al. 1978); but the insides of working landfills have remained largely unexplored. As a result, the Garbage Project developed a plan to employ archaeological methods to conduct systematic excavations at a series

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Table 1. Garbage Project Study Landfill Characteristics.

Landfill/City	Code (Date of Excavation)	Average Yearly Rain/Snow (cm)	Wells/ Trenches	Refuse Samples	Inclusive Sample Dates
Mullins Tucson, Ariz.	MUL (5/87)	27.9/—	1/9	26	1979–1985
Durham Road Fremont, Calif.	DUR (7/87)	45.7/—	3/—	21	1969–1986
Greene Valley Naperville, Ill.	GVY (8/87)	83.8/104.1	—/9	30	1977–1985
Mallard North Hanover Park, Ill.	MAL (6/88)	83.8/104.1	2/8	19	1970–1975
Sunnyvale Sunnyvale, Calif.	SUN (8/88)	33.0/—	6/1	17	1964–1980
Rio Salado Tempe, Ariz.	SAL (7/89)	20.3/—	—/8	30	1952–1971
Collier County Naples, Fla.	NAP (3/90)	134.6/—	3/2	25	1976–1988
Naples Airport Naples, Fla.	AIR (3/90)	134.6/—	2/2	10	1971–1975

Note: — = not applicable, or no data available.

of United States landfills nationwide to provide empirical field data. While these data would answer traditional archaeological questions about site formation and diachronic change, they also would be useful to opinion makers and policy planners who make decisions critical to future strategies of solid-waste management.

At present the Garbage Project has completed excavations at eight landfills from California to Florida (Table 1) and recovered and analyzed 6.71 metric tons of refuse deposited between 1952 and 1988. These digs were not designed to replace traditional types of landfill research; instead, archaeological excavations provide a new source of information to supplement and evaluate previous results and to contribute to the design of future studies. While the ultimate goal of this continuing endeavor is to collect archaeological data on contemporary discards using a methodology that will link our society to the past, this initial report relates Garbage Project data to three issues of current public concern. This first applied archaeology excavation of sanitary landfills has produced physical evidence of: (1) the contents of specific landfills and possible refinements for "national" estimates of United States landfill contents; (2) a commonly proposed link between moisture level and rate of refuse decomposition; and (3) part of the pathway of migration for heavy metals. Throughout all excavations and analyses, the Garbage Project's most useful contribution to landfill research has been to quantitatively document some of the variability within working landfills.

DATA-RECOVERY PROCEDURES

Sanitary Landfills are built of "lifts," usually composed of hundreds of cells of refuse up to 7.5 m thick that are dumped each workday and covered with a thin layer of soil each afternoon. After a lift is completed across the entire surface of a landfill, a layer of cover soil up to 1.5 m thick is added and another lift is begun on top. These lifts can be readily excavated and separated into meaningful strata and deposits using standard archaeological methods.

Excavations into landfills have included both backhoe trenches (6 m deep) and bucket-auger wells (up to 29 m deep). At landfills, specific loci were selected for excavation in an opportunistic manner inside areas stratified by the dates of refuse deposition. At the first five landfills, bucketloads of refuse were selected for sampling in a judgmental fashion to obtain refuse representative of the deposition dates and physical characteristics (such as moisture and temperature) within each landfill. In this process bias *excluded* homogeneous bucketloads of commercial wastes and construction/

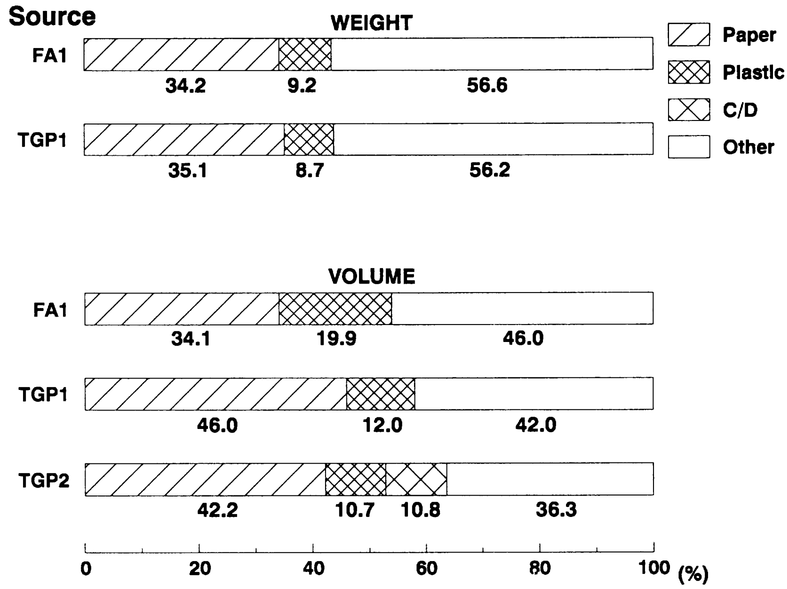

Figure 1. Percent weight and volume for paper and plastic refuse in landfills. Franklin Associates (FA) weight and volume data are "materials flows" national estimates for refuse landfilled in 1988 (Franklin Associates 1990; Franklin Associates [with the Garbage Project] 1990); volume estimates are corrected for assumed refuse moisture contents and densities. The Garbage Project (TGP-) data are percents from measurements on excavated landfill refuse compaction converted under a pressure of .87 lb/in^{-2} (61.22 g/cm^{-2}). Fines were reapportioned (TGP1) and matrix was excluded (TGP1 and -2). Construction/demolition (C/D) debris was excluded from TGP1, but included in TGP2.

demolition (C/D) debris from selection. Bucketloads from the last three landfills were taken approximately every 5 or 10 feet regardless of composition.

When a bucketload was selected as a sample refuse deposit, about 45 kg of refuse were collected. Altogether 178 such units were recovered from 56 trenches and wells at study landfills. Each sample deposit was assigned a discard-burial month/year designation based on an analysis of the clustering of dates on newspapers, other printed matter, and bottle marks in the refuse. Sample refuse was sorted into as many as 35 material composition/type categories that were recorded by weight, volume, and moisture content.

VOLUME OF LANDFILL CONTENTS

Until recently, the major solid-waste problem was the cost of transporting refuse to a disposal location. As a result, MSW has traditionally been measured by weight. Franklin Associates's MSW weight estimates for the United States, based on national production figures and on *assumptions* about discard practices, are the figures most widely cited by other researchers, policy planners, and the media. The weight percents of refuse the Garbage Project has exhumed from landfills are close to Franklin Associates's (1990) national estimates (Figure 1); for percents calculated by two such diverse methods, their degree of similarity is comforting.

Today, the most obvious MSW problem is landfill closures, with few replacements by new landfills. But landfills are not closing because they are too heavy; landfills are closing because their disposal capacity has been filled. Thus, ironically, researchers who record MSW by weight are using a measure that is largely unrelated to volume, the measure which is the key to landfill closure. Recent attempts to calculate MSW volume have centered on measurements of refuse "as discarded" on roadsides or in households (Franklin Associates [with the Garbage Project] 1990; Rathje, Hughes et al. 1989; Runkle 1976; Syrek 1989), or on MSW weight figures converted to volume using the densities of

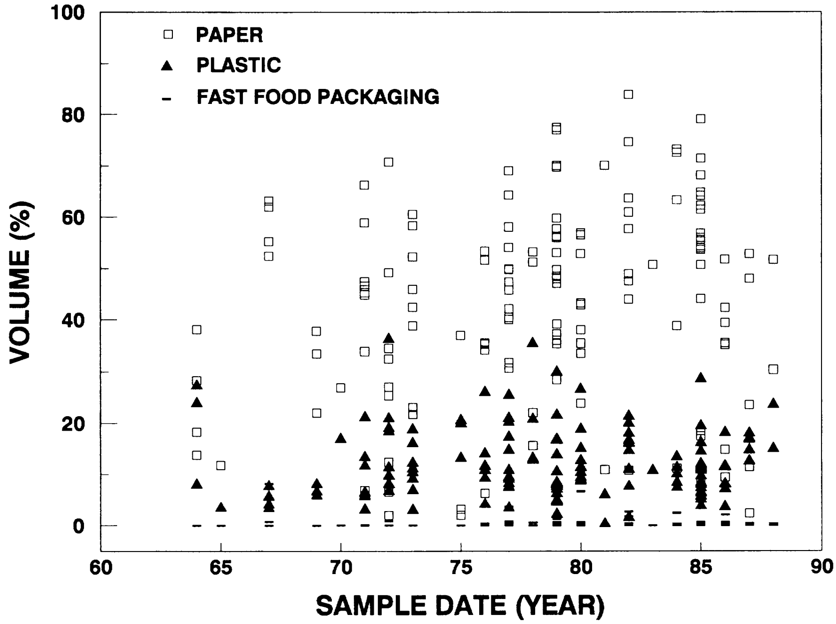

Figure 2. Compaction-converted (under .87 lb/in^{-2} [61.22 g/cm^{-2}]) refuse-category volume percents by sample refuse deposit, all landfills, 1964–1988, construction/demolition (C/D) debris and matrix excluded.

materials baled for recycling (Schlegel and Fuller 1988). The reduced volumes of specific materials that have been pressed into packer trucks, run over by heavy landfill equipment, and buried under tons more MSW usually have not been measured.

The Garbage Project's figures (Figures 1–3) represent the only volume data recorded directly from materials exhumed from landfill burial (Rathje et al. 1988, 1991; Rathje, Hughes et al. 1989). The Garbage Project's volume studies began in 1987 and measured landfill volumes on excavated refuse *as sorted* into material composition/type categories. To correct for the air (or "springback") introduced into most types of refuse (especially plastic film) during the sorting process, a low "compaction" pressure—.87 lb/in^{-2} (61.22 g/cm^{-2})—was applied to each refuse type before it was measured for its *compaction-converted* volume. The goal of this procedure was not to duplicate pressures within landfills, but to approximate the relative volumes of specific types of refuse in situ within a landfill.

In an attempt in 1989 to create a procedure to convert their estimated discard weights to landfill volumes, Franklin Associates requested that the Garbage Project excavate refuse that had been buried during the early 1980s in Los Reales Landfill (Tucson, Arizona) and compact these materials (separated into eight broad categories) to determine their densities under a pressure of 8.0 lb/in^{-2} (563.0 g/cm^{-2}). Franklin Associates used these weight-to-volume ratios combined with assumptions about refuse moisture content to convert its nationwide MSW weight estimates into nationwide percent volumes (Franklin Associates [with the Garbage Project] 1990).

While the Garbage Project and Franklin Associates use substantially different approaches, at first glance their volume figures show general agreement. For both, paper dominates landfill volume (Figure 1). Nevertheless, there are important differences: the Garbage Project's mean for compaction-converted plastic buried during the 1980s is 12 percent, while Franklin Associates's estimate of 1988 landfilled plastic is 20 percent. This difference suggests that the procedures and assumptions of both research groups should be reexamined and verified; it also underscores the difficulty in analyzing measurements on a medium so diverse and complex as MSW.

Excavations have indicated one possible reason for the differences between Franklin Associates's and Garbage Project volume figures: The densities of individual materials in landfills seem to vary greatly through time and space. The Garbage Project excavated and crushed plastic film buried

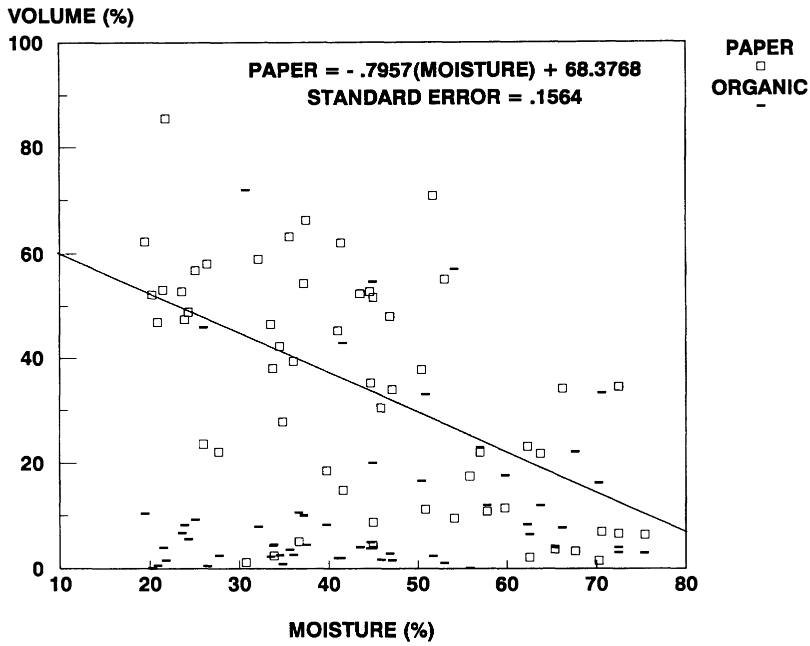

Figure 3. Moisture content (percent by weight in newspaper) and compaction-converted (under .87 lb/in^{-2} [61.22 g/cm^{-2}]) paper (r^2 = .3199) and yard/food organic volume percents for sample refuse deposits from all landfills and burial dates.

since 1974 at Harrison Road Landfill (Tucson). In crushes of six samples, this film's mean density was higher than the mean for 11 crushes of 1980s film from Los Reales Landfill in Tucson (under a compaction pressure of .87 lb/in^{-2} [61.22 g/cm^{-2}] the mean for 1983 film was 267.78 lb/yd^{-3} [158.87 kg/m^{-3}]; for 1974 film the mean was 395.86 lb/yd^{-3} [234.85 kg/m^{-3}]—t = 4.1016, $p <$ .0009; this relative difference in density occurred at all other pressures). This result could be due to different lengths of burial or time trends in different resins used in films, or both. Other 1974 refuse materials, such as rigid plastics, crushed to a higher density than those buried for a shorter time. Densities also vary considerably between and within landfills at any one time (for example, *as sorted* 1980s newspaper densities varied from means of 180.96 lb/yd^{-3} [107.36 kg/m^{-3}] [Mullins Landfill (MUL), Tucson, Arizona] to 424.95 lb/yd^{-3} [252.11 kg/m^{-3}] [Greene Valley Landfill (GVY), Naperville, Illinois], with standard deviations of 113.71 lb/yd^{-3} [67.46 kg/m^{-3}] and 149.66 lb/yd^{-3} [88.79 kg/m^{-3}], respectively), at least partly due to differences in transport and burial procedures. Overall, the range of *as sorted* densities calculated for excavated landfill refuse are evidence that excavations and crushes of a variety of fresh and old solid wastes are required to better utilize both Franklin Associates estimates and the Garbage Project compaction-converted figures to approximate the volumes of landfilled refuse.

Another issue in MSW volume estimates has been literally raised by landfill excavations. When municipalities conduct waste-characterization studies, many do not include C/D debris since private contractors are usually responsible for its disposal. In fact, because Franklin Associates follow the United States Environmental Protection Agency's definition of MSW, their weight and volume estimates of landfilled refuse exclude C/D debris. When the Garbage Project dropped its bias against C/D debris, C/D debris was measured in substantial quantities. For deposits ranging in date from 1970 to 1988 in the last three landfill excavations, the volume of C/D debris—concrete, lumber, rebar, and so on—was between 12 and 19 percent. The addition of bulky materials, such as C/D debris, reduces percentage estimates for other materials in landfills, sometimes considerably (Figure 1:TGP2).

As with all digs, one of the most valuable contributions of the Garbage Project's landfill excavations is the sense of relative proportion they provide for various discards (Figures 1 and 2). There has been some increase in items such as fast-food packaging (Figure 2) and disposable diapers (Rathje et al. 1988, 1991; Rathje, Hughes et al. 1989), which are related to the societal value placed on convenience. Nevertheless, even when not adjusted downward for the addition of either landfill matrix or C/D debris, most such commodities have a much higher visibility in the media, on local political agendas, and in the public's mind than in landfills (Rathje 1988, 1989a, 1989b, 1991). As in many other cases, an archaeologist's systematic, materialist view of a society contrasts with the written record of the inhabitants's self-perceptions.

DECOMPOSITION OF ORGANICS

Controlled laboratory studies have identified fluids as a major determinant of the rate of biological degradation of organic-refuse materials in anaerobic conditions, such as landfills (Bogner 1990; Bogner et al. 1989; Shelton and Tiedje 1984). Protocols for studying the process of biodegradation often include grinding refuse (sometimes to 2 mm), and original refuse moisture content may be increased by 200 percent. The rate of refuse degradation is measured by monitoring the production of biogas (principally methane). It is noteworthy that actual landfills rarely produce as much methane as laboratory experiments (Barlaz et al. 1990; Kinman et al. 1985).

Archaeologists have documented and analyzed the processes of degradation and biodegradation in a variety of burial contexts (e.g., Schiffer 1987; Purdy 1988). Nevertheless, none of this vast resource of relevant research has been applied by microbiologists and solid-waste engineers trying to understand and control the internal workings of landfills. As a result, the change (or lack of change) within artifacts buried in landfills remains poorly understood. The Garbage Project's excavations have unearthed such preserved perishables as heads of lettuce, Kaiser rolls, hot dogs, corncobs with their kernals intact, guacamole, and literally tons of datable, readable newspapers (Rathje 1989b, 1991). Such landfill finds, while not news to archaeologists, provide a context that draws attention to the relevance of formation processes identified in traditional archaeological contexts.

The Garbage Project's landfill data are not directly comparable to laboratory settings—landfill refuse has rarely been ground (see Ham et al. [1978] for one exception), and moisture contents are highly variable and cannot be easily raised in refuse in situ. Nevertheless, the Garbage Project attempted to investigate whether a fluid-degradation relation existed within its excavated data. Lack of decomposition was determined on the basis of whether the normal physical attributes of specific materials (such as paper) were recognizable. For all refuse samples where moisture-content analysis had been conducted, as moisture increases in refuse samples, percentage of paper decreases, from about 50 percent paper at 20 percent moisture to around 20 percent paper at 60 percent moisture (Figure 3).

While the paper-moisture data represent an initial field verification of laboratory findings, short laboratory degradation timetables are not replicated inside working landfills. Thirty-five recovered refuse samples had been buried for more than 15 years; of these, 25 (71 percent) were still composed of more than 25 percent paper by volume (see Figure 2). Given laboratory biodegradation schedules measured in weeks or months, these results are surprising. Part of the reason for this is that even landfills that receive high rainfall often contain large numbers of relatively dry deposits, but other factors are involved. Fourteen refuse samples buried before 1975 had a moisture content of more than 50 percent. The volume of eight of these sample refuse deposits was more than 25 percent recognizable and readable paper items, and all deposits contained some paper. As evidenced further by deposits with both high moisture contents and relatively high percents of yard and food organics (Figure 3), fluid is only one of several factors (such as availability of oxygen, pH, nutrients, temperature, refuse particle size, and regular movement of fluids) that are known from laboratory studies (Bogner 1990; Bogner et al. 1989; Shelton and Tiedje 1984) to be related to the decomposition of specific materials and that merit detailed field evaluations at working landfills and other archaeological sites.

Table 2. Summary of Heavy-Metal Concentrations ($\mu g\ g^{-1}$) in Landfill Fines.

Landfill	Hg	Pb	Cd	Zn	As
AIR (N = 10)					
Mean	.33	207	2.0	485	7
Median	.315	152.5	1.8	247.5	6
s.d.	.19	164	1.2	555	5
NAP (N = 23)					
Mean	.39	79	1.2	476	5
Median	.19	70	.7	350	3
s.d.	.40	50	2.4	455	5
SAL (N = 15)					
Mean	.27	122	1.7	203	13
Median	.20	70	1.0	185	14
s.d.	.37	172	2.3	89	2
SUN (N = 16)					
Mean	3.08	704	13.8	2,490	15
Median	2.60	490	17.0	1,550	12
s.d.	3.80	642	7.1	2,560	11
Control (N = 4)					
Mean	.01	63	.8	130	9
Median	.01	57	.8	128	10.5
s.d.		25	.2	48	3

Note: Incinerated deposits excluded.

THE MIGRATION OF HAZARDOUS WASTES

The processes of decomposition raise the issue of the migration of hazardous wastes within landfills. Several studies have recorded the hazardous constituents of common household commodities (Franklin Associates 1989; Office of Technological Assessment 1989; Ridgley 1982; Rugg 1988), documented the quantities of these commodities entering landfills (Duxbury and Associates 1990; Rathje et al. 1987; Russell and Meiorin 1985; Savage and Sharpe 1987; SCS Engineers 1986; Wilson and Rathje 1989), and assayed the hazardous wastes in municipal landfill leachates (Brown and Donnelly 1988; Dunlap et al. 1976; Sawhney and Kozioski 1984). The realm that remains largely theoretical is that of the internal migration processes that move materials between refuse entry and leachate formation.

Previous research by archaeologists and others suggests that concentrations of heavy metals in soils and sediments often do not migrate very far (Anderson and Nilsson 1972; Belevi and Baccini 1989; Chang et al. 1984; Hinesley et al. 1972; Waldron et al. 1979; Williams et al. 1980). Excavated landfill materials were analyzed to evaluate whether such a model is appropriate for the movement of heavy metals in landfills. Fine materials (items < ¼ inch in diameter) from 18 SUN (Sunnyvale, California), 17 SAL (Rio Salado Landfill, Arizona), 23 NAP (Collier County Landfill, Florida), 10 AIR (Naples Airport Landfill, Florida), and 4 control samples (from SAL capping materials and nearby sediments) were dried and then sieved through a .105 mm mesh to homogenize each sample. Each prepared sample was assayed for total concentrations of five elements (Hg, Pb, Zn, Cd, As) by inductively coupled plasma emission and atomic absorption (Table 2).

Arsenic concentrations were very low and the most homogeneous across fine samples. Two explanations are that either arsenic is tightly bound to its refuse carriers or little arsenic is contained in MSW. The latter is most likely the case given the low arsenic content found in fresh European refuse (Reimann 1989). For mercury, landfill samples displayed a clear separation from controls. The range of mercury concentrations in landfill samples is comparable to the range in fresh refuse samples in Europe (Reimann 1989). This suggests that mercury, in such items as floodlights and fluorescent bulbs, household batteries, and thermometers (Franklin Associates 1989; Hershkowitz 1989), occurs in an easily separable form. Lead, cadmium, and zinc concentrations yielded mixed results relative to the control (Table 2).

Within this data base there seems to be a tentative confirmation of a soil-migration model for heavy metals. For each landfill, the concentrations of heavy metals in each sample refuse deposit's fines were arrayed against: (1) date of sample refuse deposition (Figure 4), (2) moisture content of sample fines, and (3) depth of sample materials measured from the current surface. No clear-cut relations were identified. After an initial period of burial, neither the age nor the depth of sample refuse seems to dramatically alter the heavy-metal concentrations in fines. This preliminary finding suggests that the migration to fines is relatively rapid, and that once in fines, particles containing heavy metals are not likely to move down rapidly through a landfill. One of the *lowest* lead concentrations was at SUN in Well 5's 1964 refuse deposits (Sample 5-3, 350 $\mu g\ g^{-1}$). For 28 years this refuse deposit lay *directly below* Sample 5-2, which contained the well's *highest* lead concentration (2,500 $\mu g\ g^{-1}$). Sample 5-2 was a bucketload taken at a depth of 16.7 m; Sample 5-3 was the next bucketload.

The indication that total heavy-metal concentrations do not migrate very far through fines raises the possibility that given enough sample deposits, specific types of refuse (such as lead-solder-seam cans and dry-cell batteries) can be identified as associated with concentrations of specific heavy metals in fines. For example, due to rising concerns over heavy metals, in 1985 lead was reduced significantly as a constituent in many printing inks, especially in newspapers (Franklin Associates 1989). The total percent by weight of newspapers and glossy magazines is most clearly associated with lead concentrations in fines in refuse samples buried before 1985 at SUN Landfill ($n = 17$; $r^2 = .3916$; $p < .01$). The decreased use of lead in newsprint seems visible in a decline in lead levels in fines in late 1980s refuse samples from NAP Landfill (Figure 4). Such lower levels could, of course, also be due to a short duration of burial. In five or more years, lead levels in fines from freshly excavated late 1980s refuse samples will provide an ideal test case to further investigate how differing lengths of burial affect lead migration and how societal concerns and behavioral shifts leave their mark in the archaeological record.

EXCAVATION IMPLICATIONS

After World War II, landfills became the most popular mode of refuse disposal in the United States, but with little forethought given to their long-term societal and environmental consequences. Today studies addressing some of these issues are being conducted in numerous laboratory and field experiments. The Garbage Project has used archaeological methods to take the research process to working landfills and has documented that landfills are not homogeneous refuse blends; instead landfills are, as archaeologists who excavate older dumps must suspect, millions of small lenses from millions of diverse deposition episodes (spring cleaning, a child's birthday party, the aftermath of preparing the annual report at the office). Landfill digs have recorded traditional types of archaeological data on changing lifeways (including the material remains of increasing levels of consumer convenience), on how long different types of artifacts are preserved in recognizable form in their context of deposition, and on the hazards these artifacts pose to their society and to future generations. These data are also relevant to contemporary policy decisions.

First, the Garbage Project's volume data suggest that it is a monumental task to address enough products separately to cause any significant change in solid wastes. It would be more efficient to focus on broad approaches that affect large portions of behavior and resultant MSW. In practical terms, policies to identify useful resting places for inert C/D debris and to promote large-scale recycling and composting seem more likely to significantly reduce the problem of wastes than attempts to change societal values and behaviors involving conveniences in daily lifeways.

Second, rapid biodegradation is not a given in landfills. Policy decisions on whether such decomposition is desirable will require more research into the process of biodegradation in landfills and its by-products, costs, and long-term management implications.

Third, archaeological excavations can make the association between concentrations of specific

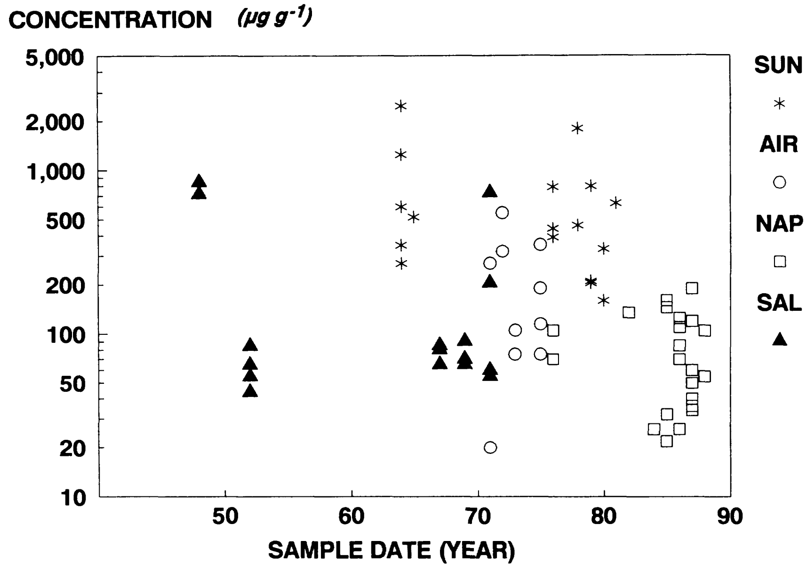

Figure 4. Lead concentrations and date of sample refuse deposition for four landfills: SUN (Sunnyvale, California), AIR (Naples Airport, Florida), NAP (Collier County, Florida), SAL (Rio Salado, Arizona).

products and the migration of potentially hazardous materials into landfill matrix measurable. Taking actual measurements under diverse environmental conditions is the next step to understanding the current and long-term legacy of today's landfills.

Those of us in the Garbage Project define archaeology as the study of the relation between human behavior, attitudes, and artifacts in all times and places (Rathje and Schiffer 1982; Reid et al. 1975). We believe that our research is as much archaeology as the excavation of refuse middens piled up in ancient times in the Near East or during historic times in New England. We are aware, however, that some archaeologists believe that our data are not old enough or that our study society is too technologically advanced for our research to be called main-stream archaeology. So be it. This paper has attempted only a validation of archaeological techniques by demonstrating the ability of archaeological methods and controls to provide data relevant to deciding contemporary public-policy issues. That is enough for now. We are all content in the certain knowledge that in another 50 years the insides of the landfills we have excavated will meet everyones' criteria for an archaeological site.

Archaeologists have been studying the past for more than one hundred years; the archaeology of contemporary landfills in differing sociocultural and physical settings has just started.

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REFERENCES CITED

Anderson, A., and K. O. Nilsson
1972 Enrichment of Trace Elements from Sewage Sludge Fertilizer in Soils and Plants. *AmBio* 1:176–179. 1:176–179.

Barlaz, M. A., R. K. Ham, and D. M. Schaefer
1990 Methane Production from Municipal Refuse: A Review of Enhancement Techniques and Microbial Dynamics. *Critical Reviews in Environmental Control* 19:557–584.

Belevi, H., and P. Baccini
1989 Long-Term Behavior of Municipal Solid Waste Landfills. *Waste Management & Research* 7:43–56.
Bogner, J. E.
1990 Controlled Study of Landfill Biodegradation Rates Using Modified BMP Assays. *Waste Management & Research* 8:329–352.
Bogner, J. E., C. Rose, and R. Piorkowski
1989 Modified Biochemical Methane Potential (BMP) Assays to Assess Biodegradation Potential in Landfilled Refuse. *Proceedings of the 5th International Conference on Solid Waste, Sludges, and Residual Materials*, pp. 53–67.
Brown, K. W., and K. C. Donnelly
1988 An Estimation of the Risk Associated with the Organic Constituents of Hazardous and Municipal Waste Landfill Leachates. *Hazardous Waste and Hazardous Materials* 5:1–30.
Chang, A. C., J. E. Warneke, A. L. Page, and J. J. Lund
1984 Accumulation of Heavy Metals in Sewage Sludge-Treated Soils. *Journal of Environmental Quality* 13:87–91.
Dunlap, W. J., D. C. Shew, J. M. Robertson, and C. R. Toussaint
1976 Organic Pollutants Contributed to Groundwater by a Landfill. In *Gas and Leachate from Landfills*, edited by E. J. Genetelli and J. Cirello, pp. 96–110. EPA-600/9-76-004, Cincinnati.
Duxbury and Associates
1990 *Summary of the Fourth National Conference on Household Waste Management.* Duxbury and Associates, Andover, Massachusetts.
Franklin Associates
1989 *Characterization of Products containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000.* Environmental Protection Agency, Washington, D.C.
1990 *Characterization of Municipal Solid Waste in the United States: 1990 Update.* Environmental Protection Agency Publication 530-SW-90-042, Washington, D.C.
Franklin Associates (with the Garbage Project)
1990 *Estimates of the Volume of MSW and Selected Components in Trash Cans and Landfills.* Council for Solid Waste Solutions, Washington, D.C.
Ham, R. K., J. J. Reinhardt, and G. W. Sevick
1978 Density of Milled and Unprocessed Refuse. *Journal of the Environmental Engineering Division* 104:109–125.
Hershkowitz, A.
1989 Batteries, What's the Problem? In *Summary of the Third National Conference on Household Hazardous Wastes*, p. 32. Duxbury and Associates, Andover, Massachusetts.
Hinesley, T. O., R. L. Jones, and G. C. Ziegler
1972 Effects on Corn by Application of Heated Anaerobically Digested Sludge. *Compost Science* 13(4):26–30.
Kinman, R. N., J. Rickabaugh, J. Donnelly, D. Nutini, and M. Lambert
1985 *Evaluation and Disposal of Waste Materials within 19 Test Lysimeters at Center Hill.* Publication Environmental Protection Agency 600/52-86/035, Cincinnati.
Office of Technological Assessment
1989 *Facing America's Trash: What's Next for Municipal Solid Wastes?* Office of Technological Assessment, Washington, D.C.
Purdy, B. A. (editor)
1988 *Wet Site Archaeology.* Telford Press, Caldwell, New Jersey.
Rathje, W. L.
1988 Landfill Garbage. *The New York Times*, January 26:A24.
1989a The Three Faces of Garbage Measurements, Perceptions, and Behaviors. *Journal of Resource Management and Technology* 17:61–65.
1989b Rubbish. *The Atlantic* 264:99–109.
1991 Once and Future Landfills. *National Geographic* 179:116–134.
Rathje, W. L., and C. K. Ritenbaugh (editors)
1984 *Household Refuse Analysis.* American Behavioral Scientist 28. Sage Publications, Beverly Hills.
Rathje, W. L., and M. B. Schiffer
1982 *Archaeology.* Harcourt, Brace, and Jovanovich, New York.
Rathje, W. L., W. W. Hughes, G. H. Archer, and D. C. Wilson
1988 Source Reduction and Landfill Myths. In *Proceedings of the 1988 National Solid Waste Forum on Integrated Municipal Waste Management*, not paginated. Association of State and Territorial Solid Waste Management Officials, Washington, D.C.
Rathje, W. L., D. C. Wilson, W. W. Hughes, and T. W. Jones
1989 *The Phoenix Report: Characterization of Recyclable Materials in Residential Solid Wastes.* Department of Public Works, City of Phoenix.

Rathje, W. L., D. C. Wilson, V. W. Lambou, and R. C. Herndon
1987 *Characterization of Household Hazardous Waste from Marin County, California, and New Orleans, Louisiana.* Publication Environmental Protection Agency 600/X-87/129, Environmental Monitoring Systems Laboratory, Las Vegas.
Rathje, W. L., W. W. Hughes, G. H. Archer, D. C. Wilson, and E. S. Cassells
1989 Digging in Landfills. In *Proceedings of the 1989 Conference on Solid Waste Management and Materials Policy,* Section III. New York State Legislative Commission on Solid Waste Management, Albany.
1991 Inside Landfills: A Preliminary Report of the Garbage Project's 1987–88 Excavation of Five Landfills. In *Proceedings of the EPA Municipal Solid Waste and Technology Conference 1989* 2:10.8–10.48. San Diego.
Reid, J. J., M. B. Schiffer, and W. L. Rathje
1975 Behavioral Archaeology: Four Strategies. *American Anthropologist* 77:864–869.
Reimann, D. O.
1989 Heavy Metals in Domestic Refuse and Their Distribution in Incinerator Residues. *Waste Management & Research* 7:57–62.
Ridgley, S. M.
1982 *Report B of The Household Hazardous Waste Disposal Project Metro Toxicant Program #1.* City of Seattle.
Rugg, M.
1988 *Sources of Lead and Cadmium in Municipal Solid Waste–A Survey of the Literature.* Camp, Dresser and McKee, Edison, New Jersey.
Runkle, S. N.
1976 *Litter Survey in Virginia.* Virginia Highway Transportation Council, Richmond.
Russell, L. J., and E. C. Meiorin
1985 *Disposal of Hazardous Waste by Small Quantity Generators: Magnitude of the Problem.* Association of Bay Area Governments, Oakland, California.
Savage, G. M., and H. Sharpe
1987 Assessment of Non-regulated Hazardous Wastes in the Seattle Area. *Waste Management & Research* 5:1590–171.
Sawhney, B. L., and R. P. Kozioski
1984 Organic Pollutants in Leachates from Landfill Sites. *Journal of Environmental Quarterly* 13:349–352.
Schiffer, M. B.
1987 *Formation Processes of the Archaeological Record.* University of New Mexico Press, Albuquerque.
Schlegel, J. A., and E. E. Fuller
1988 *Plastics Packaging Recycling: The Challenges and Opportunities.* Business Communications Company, Norwalk, Connecticut.
SCS Engineers
1986 *A Survey of Household Hazardous Waste and Related Collection Programs.* SCS Engineers, Reston, Virginia.
Shelton, D., and J. Tiedje
1984 General Method for Determining Anarobic Biodegradation Potential. *Applied and Environmental Microbiology* 47:850–857.
Syrek, D. B.
1989 *California Litter: A Comprehensive Analysis and Plan for Abatement.* California State Assembly on Resources and Land Use, Sacramento.
Waldron, H. A., A. Khera, G. Walker, G. Wibberly, and C. J. S. Green
1979 Lead Concentrations in Bones and Soil. *Journal of Archaeological Science* 6:295–298.
Williams, D. E., J. Vlamis, A. H. Pukite, and S. G. Corey
1980 Trace Element Accumulation, Movement, and Distribution in the Soil Profile from Massive Applications of Sewage Sludge. *Soil Science* 129:119–132.
Wilson, D. C., and W. L. Rathje
1989 Structure and Dynamics of Household Hazardous Wastes. *Journal of Resource Management and Technology* 17:200–206.

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