Using an Experiment in Burial Taphonomy to Delve into the Fossil Record

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ABSTRACT

To gain better insights into taphonomic processes and the conditions generally associated with becoming part of the paleontologic record, students in my first-year seminar on mass extinctions, after procuring readily available materials at a local supermarket, buried and six weeks later exhumed a wide range of organisms that had recently expired. Based on their knowledge of common fossils studied in a previous exercise and on our field-based burial experiment, students formulated and tested hypotheses about the preservational potential of different organisms and gained experience with scientific methodology involving data collection, analysis, and synthesis. This experiment successfully mimicked the very early stages in the preservation process and enabled introductory students to make reasonable predictions that they could test about the kinds of organisms that are most likely to become preserved as fossils, the conditions that are conducive for entry into the geologic record, and the rarity of fossilization.

Keywords: Education – geoscience; education – undergraduate; paleontology – general; stratigraphy, historical geology, paleoecology.

Introduction

Fossils culled from university collections for classroom use help to engender student appreciation for the diversity of life that has existed on our planet, evidence for evolution, and the aesthetic beauty of many fossilized remains. Despite estimates that one out of every million organisms has a chance of becoming preserved or that on average only 25 to 30 percent of members of marine communities find representation in the geologic record (Prothero, 1998), the variety of fossilized organisms that students routinely examine in historical geology and paleontology courses gives seemingly contradictory testimony about the record of life on Earth. Drawers upon drawers of fossils representing extinct species seem to attest to the richness of the paleontologic record rather than to its deficiencies or imperfections. Fossils representing a variety of preservational styles also appear to demonstrate that even the most delicate of organisms, including the intricate lacy exoskeletons of tiny, colonial animals (bryozoans), diaphanous films of carbonized leaves and fish, fragile insects entombed in hardened tree sap (amber), corrugated *impressions* of a clam's ribbed shell, three-dimensional replicas of a brachiopod's interior (internal casts) including muscle impressions, and traces of behavior recorded in fossilized footprints, worm burrows, sponge borings, and coprolites (petrified dung) can be fossilized. With such riches, students understandably can be seduced into overlooking the vagaries of the fossil record and may become suspicious about the validity of paleontological tenets concerning the incompleteness and selective nature of the fossil record.

To gain better insights into the rarity of fossilization as well as the conditions, or taphonomic processes, that generally are associated with becoming part of the geologic record, students in my first-year seminar on "The Sixth Extinction" interred and exhumed six weeks later a wide range of recently deceased organisms. Using readily available materials "collected" at a local supermarket, these introductory students formulated and tested their hypotheses about the preservational potential of vertebrate and invertebrate animals, plants, and fungi based on their knowledge of common fossils and fossilization processes examined in a previous exercise. This experiment was successful in simulating the very early stages in the preservational process of organisms that were buried rapidly. Furthermore, this exercise provided opportunities for introductory students to make reasonable predictions about the kinds of organisms that are most likely to become preserved as fossils, to test their predictions, and to gain important insights into the rare circumstances that contribute to the successful transformation of once-living organisms into fossils.

In addition, this field-based burial experiment, together with other hands-on exercises, enabled introductory students, most of whom did not plan to major in science, to fulfill a required "Scientific Perspectives" component of Colgate's liberal-arts core curriculum. By completing a course that emphasized methods of scientific inquiry, including careful observation and data collection, students learned to use principles of scientific reasoning in analyzing and synthesizing their results. In particular, the experiment's results promoted thoughtful consideration of why all organisms do not have an equal chance of becoming fossils, the characteristics of organisms that enhance the likelihood of being preserved, and the taphonomic processes that diminish an organism's chances of becoming fossilized. In intermediate-advanced geology courses or ones in which more time can be devoted to a series of related experiments, this exercise on post-burial changes could be a corollary to Machel's (1996) innovative use of chronologic photographs showing progressive flattening and dismemberment of roadkill specimens and to Babcock's (1998) pre-burial experiments on marine, non-marine, and terrestrial organisms.

As part of a fall-semester course, this exercise involved a three-hour period to "collect," describe, and bury the specimens, two one-hour classes to discuss and prepare for the experiment and to disinter the remains, and several days after exhumation for students to complete their syntheses as a take-home midterm. The materials used during burial and exhumation are indicated in Table 1.

The Experiment

Materials and Methods

At the beginning of a three-hour class in early September, my fourteen students and I traveled by university van to a local supermarket. In the preceding class, we had reviewed the five kingdoms of life (Margulis and Schwartz, 1988) and created a list of fourteen organisms that could be purchased locally and would represent three of the five kingdoms, including fungi, two plant phyla, three animal phyla, and three classes of chordates (Table 2). To give students an equal chance of burying the "popular" specimens (raw meat), I randomly drew students' names in succession until each student had selected a "specimen" to collect, bury, and exhume.

Burial	Exhumation
One recently deceased "specimen" per student	Latex gloves
One 40-lb. (18 kg) bag of soil per student*	Clear, gallon-size plastic bags
Data sheets	Shovels
Metric rulers and tape measures	Scissors
Camera with flash	Faucet or bucket with water
Film (allow 3-4 "before" pictures per student)	Data sheets
Shovels	Metric rulers and tape measures
Latex gloves	Camera with flash
Scissors	Film (allow 3-4 "after" pictures per student)
Twine	Marker board, marker pens, and eraser
Nails	
Plastic identification tags	
Permanent ink marker pens	
*combine two or more soil types together to create a rich, natural embalming mixture.	

Table 1. Materials used during burial and exhumation.

Buried Organisms		Exhumation Results	Taphonomic Process
K. Animalia			
P. Chordata			
Cl. Pisces:	fish (2), beheaded with bones	none	removed by scavenger
Cl. Aves:	chicken drums (6) with bones	none	removed by scavenger
Cl. Mammalia:	cow steak (1) with bone	none	removed by scavenger
	pork chop (3) with bone	none	removed by scavenger
P. Arthropoda			
Cl. Malacostraca:	shrimp (32) in shell	6 fragmentary skeletal remains	mostly decomposed
	crab legs (8) in shell	legs intact	soft-tissue decomposition
P. Mollusca			
Cl. Pelecypoda:	clams (3) in shell	shells intact but gaping	soft-tissue decomposition
K. Fungi			
P. Basidiomycota:	mushrooms (30)	none	completely decomposed
K. Plantae			
P. Angiospermophyta			
Cl. Dicotyledoneae:	onion (1) with skin	discolored but otherwise unaltered	no significant decomposition
	cucumbers (2)	partial remains except for seeds	mostly decomposed
	cantaloupe (1) with rind	intact but dimpled, discolored	partial decomposition
	head of lettuce (1)	partial remnant of single leaf	mostly decomposed
	hazelnuts (142)	missing except for 1 intact nut	removed by forager
P. Filicinophyta (Cl. Filicopsida) & P. Angiospermophyta (Cl. Dicotyledoneae):	ferns mixed with flowers (17 stems)	ferns still green, stems intact with decayed remnants of flower heads	partial decomposition

Table 2. Itemization of interred specimens, including quantity buried, exhumation results, and inferred taphonomic processes. At the time of burial, all specimens weighed approximately one lb. (0.5 kg). "None" refers to specimens that were not retrieved at the time of exhumation, and "decomposed" signifies deterioration *in situ*. Classification after Margulis and Schwartz (1988).

Once in the grocery store, students fanned out to secure their specimens. To enhance uniformity and mimic natural processes at the burial site, we had agreed that each specimen should be in as few pieces as possible, be fresh and raw rather than cooked, frozen, or processed, be unblemished, and weigh as close to a pound (0.5 kg) as possible, with weigh recorded *in situ* (weight was determined without the packaging and measured nonmetrically using the same hanging scale in the produce department). Once the experiment was explained, butchers readily repackaged a few of the meat items to accommodate our weight specifications. The total expense was $62.30 with nearly a third of the cost accounted for by the pound of mixed flower bouquets (carnations, mums, baby's breath, and ferns).

Satisfied with a successful hunt, we headed next to our local hardware store. Each student loaded into the van a sealed, plastic bag filled with either 40 lbs. (18 kg) of compost mixed with organic peat or with top soil (I had placed the $24.67 order for seven bags of each soil type a few days before). From there, we traveled to my house and backyard to set up the burial experiments. Metric rulers and tape measures as well as data sheets were provided so that before burial each student could record a detailed, written description of his or her "specimen," noting its pre-burial size, shape, color, texture, consistency, composition, and smell. Students took three to four "before burial" pictures of their specimens using a small *Instamatic* camera with flash, color print film (400 ASA), and a ruler for scale (Figures 1-2). In addition to being responsible for burying his/her own specimens, each student examined all fourteen organisms directly before burial and recorded shared information on his/her data sheets.

Next we proceeded to the burial site (Figure 3) where students made direct observations of and recorded information about the field conditions (temperature, environment (wooded), substratum (vegetated soil littered with crab apples), proximity to house and Colgate's running trails, and so on). Instead of burying the specimens directly in the ground (precluded by thin soils and hard bedrock), students worked in pairs, carefully slitting the top of each soil bag and using small shovels or their hands (protected by latex gloves) to make a rich, natural embalming medium from a mixture of the two soil types. Then they refilled each of the bags half-way, placed a specimen on top, and covered it with the remaining soil mixture as if the organism had died naturally and experienced "rapid burial." Bags were punctured with small nails for aeration and secured to tree trunks with twine, their tops were left open to the elements, and plastic tags were used to identify each bagged specimen using permanent markers. Additional photographs were taken to show the location, disposition, and caretaker of each "grave" (Figure 3). Finally, daily minimum/maximum temperatures and weather conditions were recorded during the six-week period.

Statement of Hypotheses

Immediately after the experiment was set up, each student wrote out two hypotheses. The first hypothesis predicted the preservational potential of his/her particular specimen by speculating about its physical state at the time of exhumation after six weeks of burial under the conditions observed in the field. Students acknowledged that close observation of their specimen's initial weight and morphology would enable them to deduce later the process of decay as reflected in anatomical alterations, weight loss (or gain), and changes in texture or chemical composition (Briggs and Kear, 1993). I also encouraged them to translate our very short (geologically instantaneous!) experiment into geologic time scales and to prognosticate (based on their knowledge of fossilization processes) about whether their specimen had a high, moderate, or low chance of ever becoming fossilized (assuming natural geologic conditions and given the kind of organism they had buried). Many of the students provided detailed speculations about how their buried specimens would be altered, for example, predicting changes in smell (from fresh to rotten or rancid), consistency (from firm to soft or pulpy), and texture (from smooth to irregular) caused by the degradational activities of microorganisms and other decomposing agents.

In formulating a second hypothesis, the students independently ranked all 14 of the specimens based on their prediction of the relative preservational potential of the buried organisms. With annotated explanations, they assigned a 1 to the specimen that they thought would have the *best* chance of leaving all or part of itself to become fossilized (assuming under natural conditions and over time), a 2 to the specimen with the next highest preservational potential, and so on; number 14 was for the specimen that they thought would have the *least* preservational potential. Most students ranked either the clams or the mammal specimens with the highest preservational potential and the soft-bodied organisms (lettuce, flowers, and mushrooms) with the least chance of preservation. These predictions were an important record to which students could refer when they analyzed and synthesized their exhumed results.

Exhumation

In mid-October six weeks after burial, we returned to the grave sites for exhumation (Table 1). Using shovels, latex gloves, and one-gallon clear plastic bags, students located their bagged specimens and noted similarities or differences in their disposition from six weeks before (one bag was toppled and others had visible tears). Next they gingerly used their hands and shovels to locate their specimens inside the bags, gently sifting through the soil and searching nearby for organic remains. Remnants from each original specimen were collected in the small plastic bags and were washed (an outside faucet was helpful) or brushed carefully to remove clinging soil particles.

On their data sheets, students completed a detailed, written description of their "specimens," noting post-burial size, shape, color, texture, consistency, composition, and smell. Students took three to four "after exhumation" pictures of their specimens, again using a ruler for scale. As some of the unearthed remains were difficult to identify, it was helpful to

Figure 1. Photographs showing "before" and "after" pictures of organisms that were buried. A) clams before burial; b) clams after exhumation; C) mushrooms before burial; D) bag in which mushrooms were buried showing no evidence of tampering at time of exhumation; E) cucumbers before burial; and F) partial remains of exhumed cucumbers; note intact seeds (circled). Rulers in A and E are 30 cm in length; calipers in C are 12 cm long.

have handy a marker board and pens to provide labels for the objects during photography (Figures 1-2). Students also examined each other's disinterred materials directly and shared information to be recorded on their data sheets. Finally, we made a return trip to the supermarket to determine weight loss during burial. Surreptitiously, we reweighed the exhumed remains (enclosed by *clean* plastic bags) using furtive demeanor and the same hanging scale as before. A few students stood as lookouts so as to avoid any unnecessary confrontation in the produce department. For comparative purposes, the remnants of the crab, clams, flowers, cantaloupe, and onion were reburied at the field site to be exhumed at an undetermined date in the future.

Results

As summarized in Table 2, 36% of the interred objects had disappeared without a trace (fish, steak, pork chops, chicken, mushrooms); 21% had undergone nearly complete disintegration (lettuce, cucumbers) or represented <1% of the original quantity (nuts); 36% existed in an incomplete, fragmentary, or altered state (shrimp, crab, clams, flowers, cantaloupe); and only 7% remained largely unaltered (onion). Large tears

Figure 2. Photographs showing "before" and "after" pictures of organisms that were buried. A) onion before burial; B) onion after exhumation; note discoloration but general lack of alteration; C) cantaloupe after exhumation showing discoloration, dimpling, and hardened rind; D) bag in which chicken legs were buried shows at time of exhumation a large tear (arrow) near base as evidence of vandalizing scavengers. Rulers in A and C are 15 cm and 30 cm in length, respectively.

and holes in the bags containing the fish, steak, chops, chicken (Figure 2), and nuts suggested that those sites had been vandalized by scavenging or foraging organisms. Remarkably one nut was recovered whole and intact near its original grave site, but no bones, vertebrate fragments, or teeth were retrieved in proximity to the burial sites. The small size of the holes

Figure 3. Burial site in wooded area showing Stephen Lee for scale and disposition of 40-lb. (18 kg) bag of soil containing entombed specimen.

suggested the activities of local inhabitants, such as raccoons, opossums, and (or) squirrels; supporting but circumstantial evidence was observed nearby in the form of muddy footprints left by a raccoon(s).

The bags that had contained the mushrooms (Figure 1), lettuce, and cucumbers, however, showed no evidence of disturbance thus leading to the interpretation that those objects had dewatered and experienced natural disintegration *in situ*. Not surprisingly, the seeds of the cucumber were remarkably intact, but the cucumber's flesh was a "highly decomposed, slimy, green ooze" (Figure 1). Some evidence of tampering was evident in bags that had contained the shrimp, crab, flowers, and onion, but most of the original objects were recovered, albeit some as incomplete or disintegrated fragments. The crabs' exoskeletons were relatively resistant to decay, but the shrimp and crabmeat had suffered considerable cuticular and (or) soft-tissue decomposition.

As was predicted by most of the students, the clam shells were robust and intact (Figure 1), although the soft parts had decayed forming a "disgusting mess with a mucous-like quality." The flowers had deteriorated except for the stems, and the ferns were largely unaltered and still bright green. The rind of the cantaloupe was discolored, dimpled, and had hardened during desiccation (Figure 2). Surprising to most of the students was the durability of the onion, which – as any gardener fond of root vegetables might have predicted – experienced only a slight change in color but exhibited no other visible signs of alteration (Figure 2).

Discussion

During an exercise with fossil specimens the week before commencing the burial experiment, my class had discussed the incompleteness of the fossil record and had considered a range of geologic phenomena that can either enhance or detract from the preservation of organisms as fossils. To encourage a thoughtful synthesis of the experiment's results, students completed a take-home midterm, which comprised a detailed report of the experiment's purpose, materials and methods, hypotheses, results, discussion, literature-based comparison with actual fossilized remains, conclusions, and reference to "before" and "after" burial photographs. In their reports, many students acknowledged that most organisms likely to be preserved in the fossil record will be incomplete because of the rapid decomposition of soft tissues. By ranking either the clams or the mammal specimens with the highest preservational potential, indeed most of the class logically reasoned that "hard parts," like biomineralized skeletons, teeth, and shell, or the durable organic constituents of plants, were more apt to fossilize than were soft-bodied vegetables and fungi. Furthermore, most of the class recognized that the hollow bones of birds and the thin, delicate bones of fish were not destined to become fossilized as often as the more robust skeletons of other vertebrates.

Artificially burying aquatic organisms in soil bags on land did not preclude most students from postulating that terrestrial organisms, because of the reduced chances for rapid burial in many dry-land environments, are less well represented as fossils than are marine or fresh-water organisms. Some students suggested that even after long-term burial some organic remains might not be preserved because the environments in which they had been buried were not conducive to fossilization. Students who made use of the daily weather records inferred that their specimens had deteriorated rapidly because of the unusually sunny, dry, and warm weather we had experienced in late summer (average daily temperature was 58 degrees F), thus confirming what other experiments have shown about the correlation between rapid rates of organic decomposition and elevated temperatures (Kidwell and Baumiller, 1990; Meyer, 1991; Davis and Briggs, 1998). A few students also recognized that some of the soft-bodied specimens (for example, onion) underwent very slow rates of decomposition once buried and thus survived better structurally over the short-term but lacked durability to leave any preservable remains over geologically significant intervals of time. Another student acknowledged the difficulty a paleontologist might encounter in piecing together the remains of individual organisms that had suffered dismemberment and transportation.

These ideas were reinforced in the comparative study each student undertook as part of the midterm to determine if organisms similar to those each had buried were represented by fossils from the rock record. Library resources and information available on the web, carefully scrutinized, helped students ascertain the abundance or rarity of particular types of fossil remains and provided evidence in support of the overall findings and conclusions of the experiment. Viewing the fossil record as a comparative set of natural "experiments" that the earth conducted long ago (Allmon, 1997) also emphasized the scientific value of performing many tests to determine whether predictions are borne out and, if they are not, being prepared to formulate revised hypotheses and redesign experiments.

The most surprising outcome of the experiment was that none of the students had given serious consideration to the impact that scavenging or foraging organisms might have on the fossilization potential of a significant proportion of the specimens we buried. Thus virtually all students overestimated the preservational potential of *individual* vertebrate organisms because of their durable parts and were overly pessimistic about the short-term fate of the onion, ferns, and cantaloupe. Some students, upon discovering that they had no objects to exhume, assumed that the experiment had failed and that, consequently, they would flunk the midterm, or that it was impossible to assess the fossilization potential of the vertebrates because they were missing or because "unnatural" and "unfair" agents had interrupted the preservational process.

Upon further reflection and discussion, students recognized that many physical, biological, and chemical phenomena at work on or below the earth's surface (for example, wind, rain, erosion, predators, scavengers, dissolution, diagenesis, and so forth) can increase or diminish an organism's chances of becoming preserved. In particular, most students came to the realization that predators and scavengers can play a significant role in disarticulating and transporting organisms, in posthumously mixing together creatures that in life did not share the same habitat, or in completely destroying, through abrasion and (or) ingestion, organic remains that might have become fossilized (Plotnick and others, 1988; Davis and Briggs, 1998).

Summary

This experiment gave students the opportunity to investigate taphonomic processes, particularly those summarized here, that paleontologists have identified through numerous burial experiments to be conducive or detrimental to fossilization. Marine and fresh-water organisms have a better chance of being preserved than do inhabitants of dry, terrestrial environments because aquatic organisms have a greater likelihood of becoming buried rapidly (Shipman, 1981; Seldon, 1990). Postmortem changes to terrestrial and aquatic organisms occur quickly, generally with signs of decay that are significant enough to be detected in a few days or weeks (Meyer, 1971; Hill, 1980; Plotnick, 1986; Plotnick and others, 1988; Allison and Briggs, 1991; Meyer, 1991; Baumiller and Ausich, 1992; Babcock, 1998; Davis and Briggs, 1998). Elevated temperatures promote the rapid growth of bacteria and other decomposing microorganisms, which contribute to enhanced rates of decay (Davis and Briggs, 1998) but generally are a secondary process to changes induced very early by predatory or scavenging organisms (Plotnick, 1986). Carnivorous animals cause extensive damage to soft tissue and hard parts and thus exert a strong influence on the preservational potential of those organic remains that may survive the activities of predatory and scavenging organisms in pre- and post-burial environments (Davis and Briggs, 1998).

Contrary to Babcock's (1998) conclusions, our experiment showed that considerable post-burial changes occur in organisms that were entombed rapidly before they had experienced any substantial pre-burial modifications in morphology. Thus we recognized that factors in the *post*-burial environment also exert considerable influence on the types of organic remains that become candidates for fossilization after experiencing entombment and some degree of alteration. Furthermore, more than a third of the specimens we buried had disappeared without a trace (with the exception of one nut), demonstrating the significant impact of scavenging and foraging creatures on the preservational potential of many types of organisms. Rapid burial may be conducive to fossilization, but our study confirmed what other research has shown – that a significant percentage of organisms are likely to be preserved only if they are buried deeply enough to avoid detection by scavengers (and foragers) (Hill, 1980; Plotnick, 1986; Allison and Briggs, 1991; Davis and Briggs, 1998). Other processes that may diminish the taphonomic loss induced by scavenging organisms include catastrophic mass burials, which may produce a sudden influx of carcasses too numerous to be processed fully by local predators and scavengers (Behrensmeyer, 1991) or burial under anoxic conditions in an environment that is inhospitable to burrowing scavengers (Kidwell and Baumiller, 1990; Donovan, 1991; Allison and Briggs, 1991).

In a paleontology course, these ideas could serve as a perfect catalyst for discussions about the concept of "escalation" and the impact of the activities of carnivores on evolutionary and taphonomic processes (Vermeij, 1977). Also, this experiment could be designed to dovetail intellectually with pre-burial experiments developed by Babcock (1998) or be made more elaborate by: (1) burying organisms in protected cages and (or) under different thicknesses of sediment to determine the taphonomic threshold of burrowers, scavengers, and foragers (Plotnick, 1986; Plotnick and others, 1988; Briggs and Kear, 1993); (2) burying, exhuming, and reburying specimens at closely spaced intervals to monitor the stages in decay, disintegration, and disarticulation over a few weeks (Plotnick and others, 1988); (3) using burial media of different compositions and textures to ascertain the effect of sediment composition and grain size on preservation; or (4) using comparative burials in the lab to determine decay rates as a function of temperature and (or) oxygen concentrations (Kidwell and Baumiller, 1990; Briggs and Kear, 1993; Babcock, 1998).

Conclusions

In my introductory course, this simple experiment was successful in generating among first-year students a deeper understanding of the paleontologic record, taphonomic processes, and the rarity of fossilization. In particular by fostering an appreciation for why certain organisms occur as fossils with greater frequency than do other kinds of organisms, it provided an enjoyable means by which students could more critically evaluate the flawed but fecund fossil record. As a result, students learned that the paleontologic record, despite certain deficiencies in continuity and context, is an extraordinary chronicle of past life even though most organisms that ever lived on our planet are unlikely to have contributed preserved remains to it. Additionally at minimal monetary expense, this exercise yielded rich results by creating opportunities to engage introductory students in the scientific process and was fertile ground for cultivating meaningful discussions about the evolution of life, the earth's history, and extinction episodes past and present.

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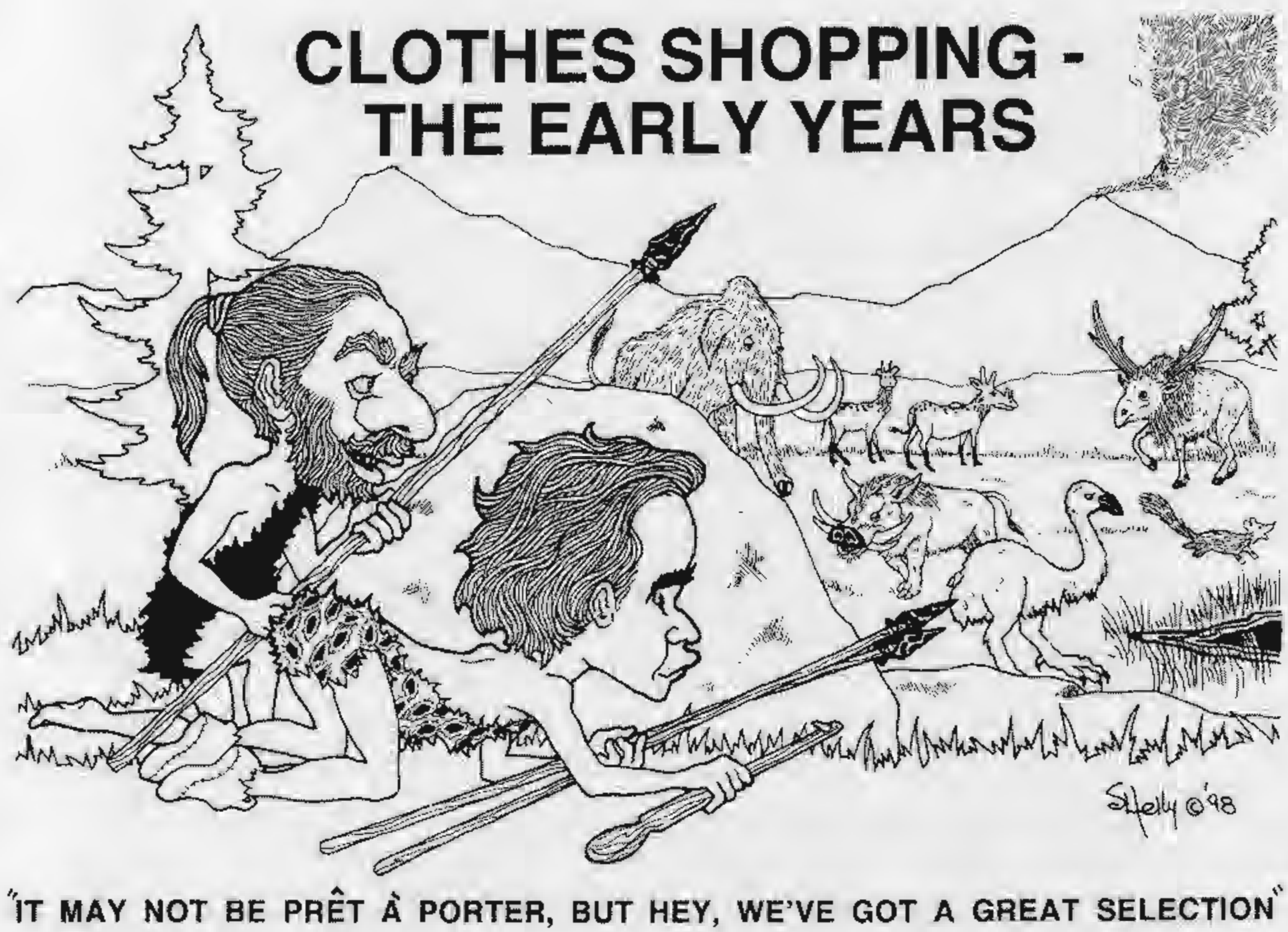

"IT MAY NOT BE PRÊT À PORTER, BUT HEY, WE'VE GOT A GREAT SELECTION"