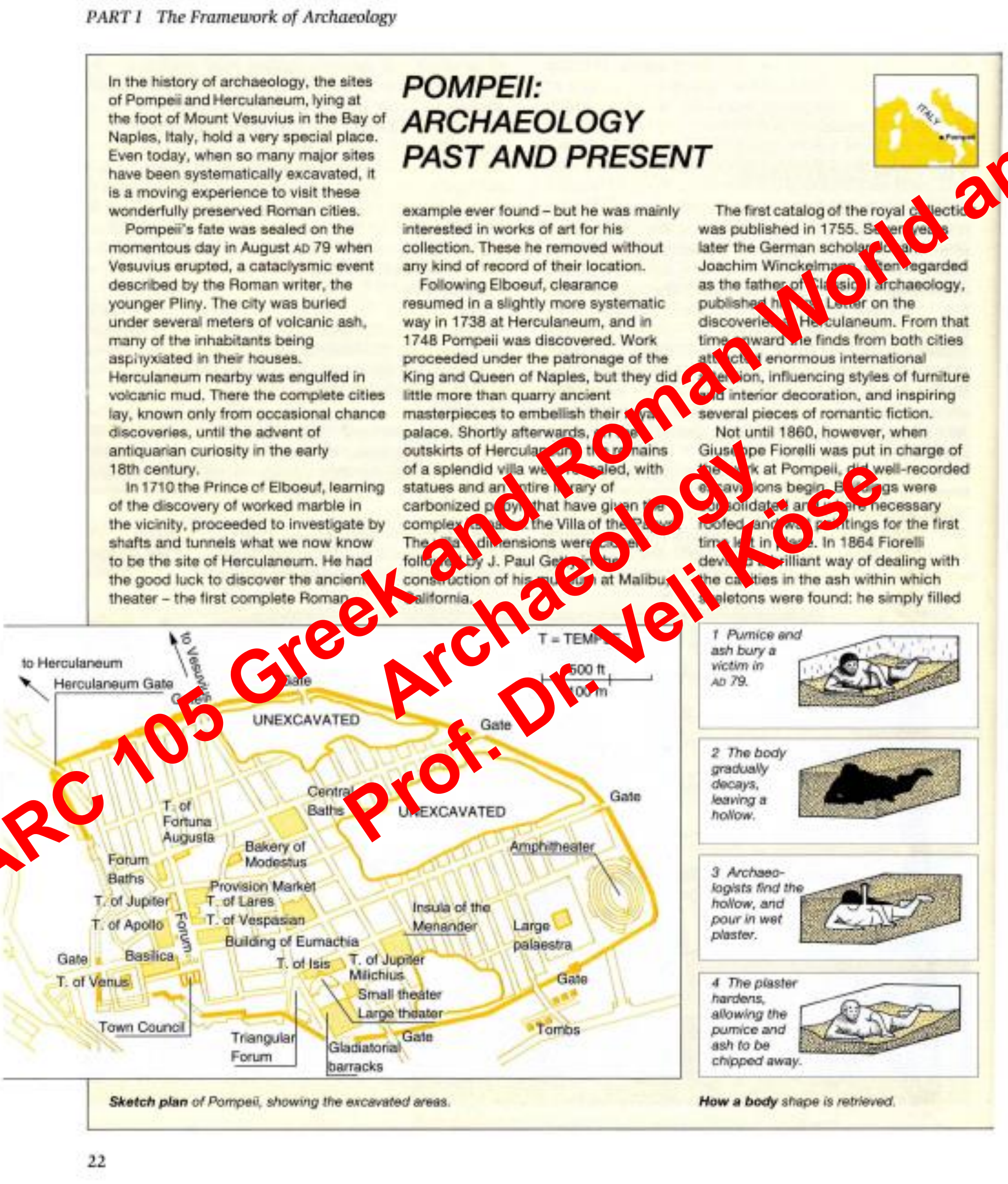


POMPEII: ARCHAEOLOGY PAST AND PRESENT

In the history of archaeology, the sites of Pompeii and Herculaneum, lying at the foot of Mount Vesuvius in the Bay of Naples, Italy, hold a very special place. Even today, when so many major sites have been systematically excavated, it is a moving experience to visit these wonderfully preserved Roman cities.

Pompeii's fate was sealed on the momentous day in August AD 79 when Vesuvius erupted, a cataclysmic event described by the Roman writer, the younger Pliny. The city was buried under several meters of volcanic ash, many of the inhabitants being asphyxiated in their houses. Herculaneum nearby was engulfed in volcanic mud. There the complete cities lay, known only from occasional chance discoveries, until the advent of antiquarian curiosity in the early 18th century.

In 1710 the Prince of Elboeuf, learning of the discovery of worked marble in the vicinity, proceeded to investigate by shafts and tunnels what we now know to be the site of Herculaneum. He had the good luck to discover the ancient theater – the first complete Roman example ever found – but he was mainly interested in works of art for his collection. These he removed without any kind of record of their location.

Following Elboeuf, clearance resumed in a slightly more systematic way in 1738 at Herculaneum, and in 1748 Pompeii was discovered. Work proceeded under the patronage of the King and Queen of Naples, but they did little more than quarry ancient masterpieces to embellish their royal palace. Shortly afterwards, on the outskirts of Herculaneum, the remains of a splendid villa were revealed, with statues and an entire library of carbonized papyri that have given the complex its name, the Villa of the Papyri. The villa's dimensions were closely followed by J. Paul Getty in the construction of his museum at Malibu, California.

The first catalog of the royal collection was published in 1755. Several years later the German scholar Johann Joachim Winckelmann, often regarded as the father of Classical archaeology, published his first Letter on the discoveries at Herculaneum. From that time onward the finds from both cities attracted enormous international attention, influencing styles of furniture and interior decoration, and inspiring several pieces of romantic fiction.

Not until 1860, however, when Giuseppe Fiorelli was put in charge of the work at Pompeii, did well-recorded excavations begin. Buildings were consolidated and where necessary roofed, and wall paintings for the first time left in place. In 1864 Fiorelli devised a brilliant way of dealing with the cavities in the ash within which skeletons were found: he simply filled

Sketch plan of Pompeii, showing the excavated areas.

How a body shape is retrieved.

them with plaster of Paris. The ash around the cavity acted as a mold, and the plaster took the accurate shape of the decayed body. (In a recent technique, the excavators pour in transparent glass fiber. This allows bones and artifacts to be visible.)

During the present century, Amedeo Maiuri excavated at Pompeii between 1924 and 1961, revealing extensive remains of earlier phases of the town beneath the AD 79 ground level. In recent years his work has been supplemented by limited excavations carried out by Paul Arthur. Another recent project under the direction of Roger Ling has focused on the detailed analysis of one insula, or city block, the Insula of the Menander. The project has revealed changes in the property boundaries and uses of different parts of the insula that have thrown much new light on the social and economic development of Roman Pompeii.

Pompeii remains the most complete urban excavation ever undertaken. The town plan is clear in its essentials, and most of the public buildings have been investigated, along with innumerable shops and private houses. Yet the potential for further study and interpretation is enormous.

Today it is not difficult for the visitor to Pompeii to echo the words of Shelley in his Ode to Naples, written more than a century and a half ago:
"I stood within the city disinterred; / And heard the autumn leaves like light footfalls/Of spirits passing through the streets; and heard/The mountain's slumberous voice at intervals/Thrill through those roofless halls."

A view along *the Street of the Tombs, Pompeii (top left), an engraving of 1824. In the wall painting from the House of the Vettii, Pompeii (center left), gazelles draw the god of love, Cupid, in a chariot. A plaster cast (left) recreates the shape of a Pompeian struck down in flight. Conditions of preservation at Pompeii are remarkable: for example, many carbonized loaves of bread have survived (right).*

UNDERWATER ARCHAEOLOGY

Underwater archaeology is generally considered to have been given its first major impetus during the winter of 1853–54, when a particularly low water level in the Swiss lakes laid bare enormous quantities of wooden posts, pottery, and other artifacts. From the earliest investigations, using crude diving-bells, it has developed into a valuable complement to work on land. It encompasses a wide variety of sites, including wells, sink holes, and springs (e.g. the great sacrificial well at Chichén Itzá, Mexico); submerged lakeside settlements (e.g. those of the Alpine region); and marine sites ranging from shipwrecks to sunken harbors (e.g. Caesarea, Israel) and drowned cities (e.g. Port Royal, Jamaica).

The invention in recent times of miniature submarines, other submersible craft, and above all of scuba diving gear has been of enormous value, enabling divers to stay underwater for much longer, and to reach sites at previously impossible depths. As a result, the pace and scale of discovery have greatly increased over the last few decades. For example, in the Mediterranean and Black Sea about 1000 shipwrecks are now known for the Classical and medieval periods.

Underwater Reconnaissance

Geophysical methods are as useful for finding sites underwater as they are for locating land sites (see diagram). For example, in 1979 it was magnetometry combined with side-scan sonar that discovered the *Hamilton* and the *Scourge*, two armed schooners sunk during the War of 1812 at a depth of 90 m (295 ft) in Lake Ontario, Canada. Nevertheless, in regions such as the Mediterranean the majority of finds have resulted from methods as simple as talking to local sponge divers, who collectively have spent thousands of hours on the seabed.

Underwater Excavation

Excavation underwater is complex and expensive (not to mention the highly demanding post-excavation conservation and analytical work that is also required). Once underway, the excavations may involve shifting vast quantities of sediment, and recording and removing bulky objects as diverse as storage jars (amphorae), metal ingots, and cannons. George Bass, founder of the Institute of Nautical Archaeology in Texas, and others have developed many helpful devices, such as baskets attached to balloons to raise objects, and air lifts (suction hoses) to remove sediment (see diagram). If the vessel's hull survives at all, detailed drawings must be made so that specialists can later reconstruct the overall form and lines, either on paper or in three dimensions as a model or full-scale replica (see box, pp. [illegible]). In some rare cases, like that of England's *Mary Rose* (16th century AD), preservation is sufficiently good for the remains of the hull to be raised – funds permitting.

Nautical archaeologists have now excavated more than 100 sunken vessels, revealing not only how they were constructed but also many insights into shipboard life, cargoes, trade routes, early metallurgy and glassmaking. We look in more detail at two projects: the Red Bay Wreck, Canada (pp. [illegible]) and the Uluburun Wreck, Turkey (pp. 358–59).

Three methods *(near right) of geophysical underwater survey. (1) The proton magnetometer is towed well behind the survey boat, detecting iron and steel objects (e.g. cannons, steel hulls) that distort the earth's magnetic field. (2) Side-scan sonar transmits sound waves in a fan-shaped beam to produce a graphic image of surface (but not subsurface) features on the seafloor. (3) The sub-bottom profiler emits sound pulses that bounce back from features and objects buried beneath the seafloor.*

Underwater excavation *techniques (far right): at left, the lift bag for raising objects; center, measuring and recording finds in situ; right, the air lift for removing sediment.*

THE RED BAY WRECK: DISCOVERY AND EXCAVATION

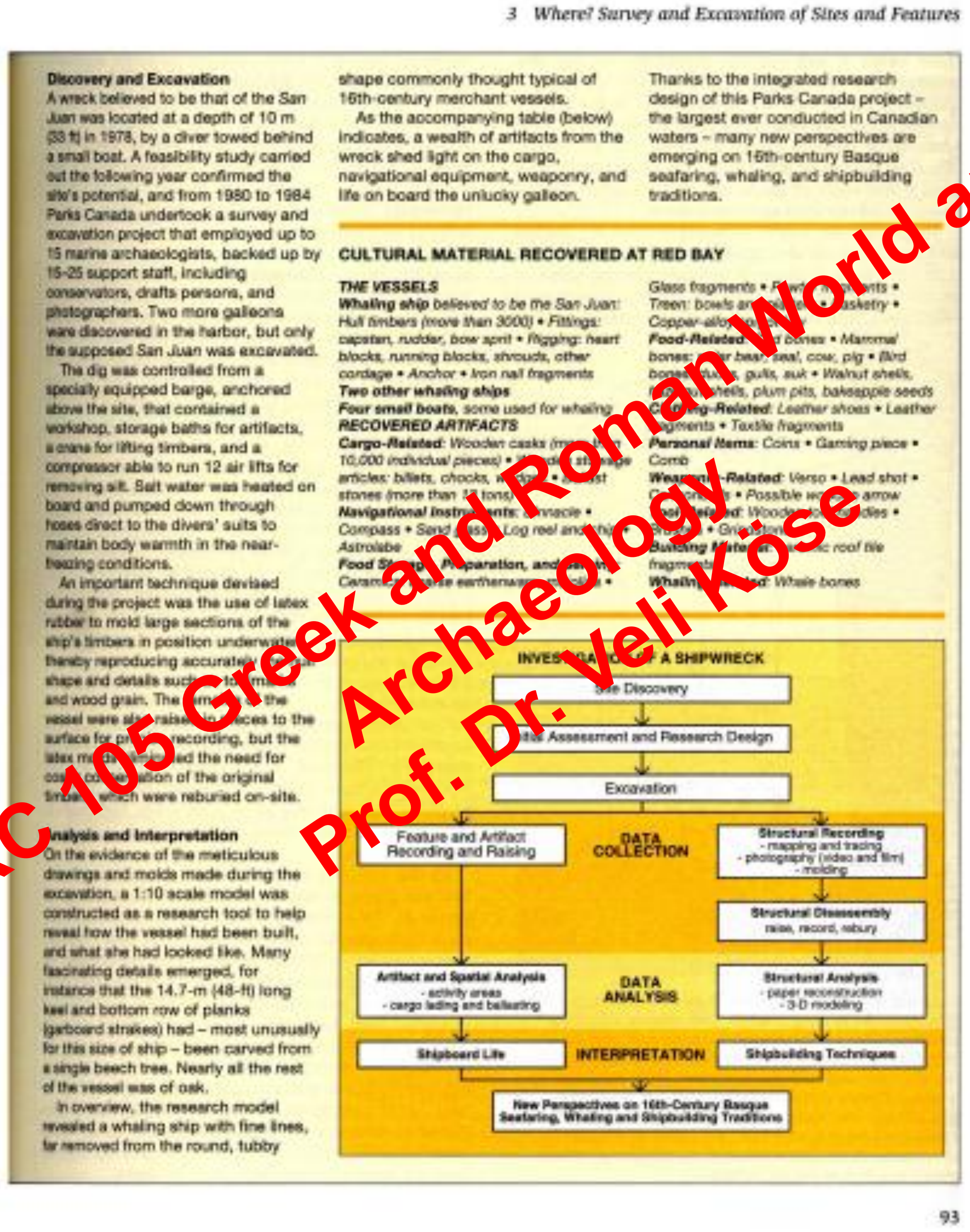
Underwater archaeology, in conjunction with archival research and land archaeology, is beginning to yield a detailed picture of whaling undertaken by Basque fishermen at Red Bay, Labrador, in the 16th century AD. The Basques were the largest suppliers to Europe at this time of whale oil – an important commodity used for lighting and in products such as soap.

In 1977, prompted by the discovery in Spanish archives that Red Bay had been an important whaling center, the Canadian archaeologist James A. Tuck began an excavation on the island closing Red Bay harbor. Here he found remains of structures for rendering blubber into whale oil. The next year, the nautical archaeologist Robert Grenier led a Parks Canada team in search of the Basque galleon San Juan, which the archives said had sunk in the harbor in 1565.

Model, at a scale of 1:10, to show how the skeleton's surviving timbers may have fitted together.

Project director *Robert Grenier (top) examines the remains of an astrolabe (navigational instrument) from Red Bay.*

Structural plan *of the wreck on the harbor bottom (2-m grid squares).*



Discovery and Excavation

A wreck believed to be that of the *San Juan* was located at a depth of 10 m (33 ft) in 1978, by a diver towed behind a small boat. A feasibility study carried out the following year confirmed the site's potential, and from 1980 to 1984 Parks Canada undertook a survey and excavation project that employed up to 15 marine archaeologists, backed up by 15–25 support staff, including conservators, drafts persons, and photographers. Two more galleons were discovered in the harbor, but only the supposed *San Juan* was excavated.

The dig was controlled from a specially equipped barge, anchored above the site, that contained a workshop, storage baths for artifacts, a crane for lifting timbers, and a compressor able to run 12 air lifts for removing silt. Salt water was heated on board and pumped down through hoses direct to the divers' suits to maintain body warmth in the near-freezing conditions.

An important technique devised during the project was the use of latex rubber to mold large sections of the ship's timbers in position underwater, thereby reproducing accurately [illegible] shape and details such [illegible] tool marks and wood grain. The [illegible] of the vessel were also raised in pieces to the surface for [illegible] recording, but the latex molds [illegible] the need for costly conservation of the original timbers, which were reburied on-site.

Analysis and Interpretation

On the evidence of the meticulous drawings and molds made during the excavation, a 1:10 scale model was constructed as a research tool to help reveal how the vessel had been built, and what she had looked like. Many fascinating details emerged, for instance that the 14.7-m (48-ft) long keel and bottom row of planks (garboard strakes) had – most unusually for this size of ship – been carved from a single beech tree. Nearly all the rest of the vessel was of oak.

In overview, the research model revealed a whaling ship with fine lines, far removed from the round, tubby shape commonly thought typical of 16th-century merchant vessels.

As the accompanying table (below) indicates, a wealth of artifacts from the wreck shed light on the cargo, navigational equipment, weaponry, and life on board the unlucky galleon.

Thanks to the integrated research design of this Parks Canada project – the largest ever conducted in Canadian waters – many new perspectives are emerging on 16th-century Basque seafaring, whaling, and shipbuilding traditions.

CULTURAL MATERIAL RECOVERED AT RED BAY

THE VESSELS

Whaling ship *believed to be the San Juan: Hull timbers (more than 3000) • Fittings: capstan, rudder, bow sprit • Rigging: heart blocks, running blocks, shrouds, other cordage • Anchor • Iron nail fragments*

Two other whaling ships

Four small boats, *some used for whaling*

RECOVERED ARTIFACTS

Cargo-Related: *Wooden casks (more than 10,000 individual pieces) • Wooden stowage articles: billets, chocks, wedges • Ballast stones (more than [illegible] tons)*

Navigational Instruments: *Binnacle • Compass • Sand glass • Log reel and chip • Astrolabe*

Food Storage, Preparation, and Dining: *Ceramics: coarse earthenware, [illegible] • Glass fragments • Pewter fragments • Treen: bowls and [illegible] • Basketry • Copper-alloy [illegible]*

Food-Related: *[illegible] bones • Mammal bones: polar bear, seal, cow, pig • Bird bones: ducks, gulls, auk • Walnut shells, [illegible] shells, plum pits, bakeapple seeds*

Clothing-Related: *Leather shoes • Leather fragments • Textile fragments*

Personal Items: *Coins • Gaming piece • Comb*

Weaponry-Related: *Verso • Lead shot • [illegible] • Possible wooden arrow*

Tool-Related: *Wooden tool handles • Brushes • Grindstone*

Building Material: *Ceramic roof tile fragments*

Whaling-Related: *Whale bones*

INVESTIGATION OF A SHIPWRECK

Site Discovery

Site Assessment and Research Design

Excavation

DATA COLLECTION

Feature and Artifact Recording and Raising

Structural Recording
- mapping and tracing
- photography (video and film)
- molding

Structural Disassembly
raise, record, rebury

DATA ANALYSIS

Artifact and Spatial Analysis
- activity areas
- cargo lading and ballasting

Structural Analysis
- paper reconstruction
- 3-D modeling

INTERPRETATION

Shipboard Life

Shipbuilding Techniques

New Perspectives on 16th-Century Basque Seafaring, Whaling and Shipbuilding Traditions

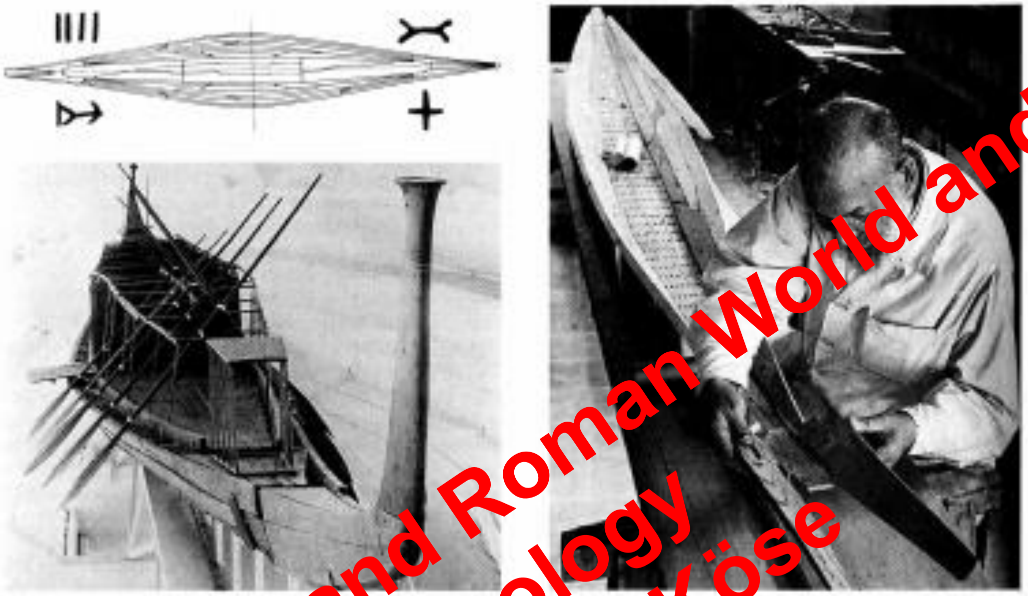
Bronze Age trackway, *more than 3500 years old, called the Eclipse Track. The excavated length consisted of over 1000 hurdles, short track sections whose interwoven rods could only have been produced from a managed woodland, where tree stumps were deliberately cut back to encourage young, straight shoots.*

Wheeled vehicles first appeared in the 4th millennium BC in the area between the Rhine and the Tigris; the earliest wheels were solid discs, either single-piece (cut from planks, not transverse slices of tree-trunks) or composite. Spoked wheels were developed in the 2nd millennium for lighter, faster vehicles such as chariots, for instance ones found in Tutankhamun's tomb (box, pp. 58–59). Wheeled transportation clearly had a huge impact on social and economic development, but nevertheless had a very limited geographical spread when compared with the ubiquitous wooden technology displayed in watercraft.

Investigating Watercraft. Until the 19th century all boats and ships were made predominantly of wood, and in perhaps no other area of pre-industrial technology did the world's craftspeople achieve such mastery as in the building of wooden vessels of all kinds, from small riverboats to great oceangoing sailing ships. The study of the history of this technology is a specialized undertaking, far beyond the scope of the present book to summarize in any detail. But it would be wrong to imagine that archaeology has little to contribute to what is already known from historical records. For the prehistoric period such records are of course absent, and even in historic times there are great gaps in knowledge that archaeology is now helping to fill.

The richest source of archaeological evidence by far comes from the preserved remains of ships uncovered by underwater archaeology (box, p. 91). In the late 1960s, the excavation of a 4th-century BC Greek ship off Kyrenia, Cyprus, showed that vessels of that period were built with planks held together by mortise-and-tenon joints. The recent excavation by George Bass and his colleagues of a wreck at Uluburun, near Kaş, off the south coast of Turkey (box, pp. 358–59), has now revealed a vessel 1000 years older that uses the same technique.

At the beginning of this chapter we stressed how important it is for archaeologists to obtain the advice of craftspeople in the technology concerned. This is particularly true for the accurate understanding of shipbuilding. J. Richard Steffy, of the Institute of Nautical Archaeology in Texas, has an unrivaled practical knowledge of the way ships are (or were) put together, a knowledge he has applied to excavated vessels in the Old World and the New. In his judgment the best way to learn how a ship was built and functioned is to refit the excavated timbers in the most likely original shape of the vessel, achieved through analysis of the excavation and painstaking trial and error, with the aid of exact copies at one-tenth scale of the remaining timbers (box, pp. 92–93). This was the



Reconstructing the oldest ship in the world. In 1954 the dismantled parts of a cedarwood boat were found buried in a pit on the south side of the Great Pyramid of King Cheops at Giza, Egypt. (Top left) One important clue to the reconstruction proved to be the four classifying signs marked on most of the timbers that indicated to which of the four quarters of the ship the timbers belonged. (Right) Hag Ahmed Youssef used a small model to help in the task of reconstruction. (Left) After 14 years of work, the 1244 pieces of the ship were finally reassembled.

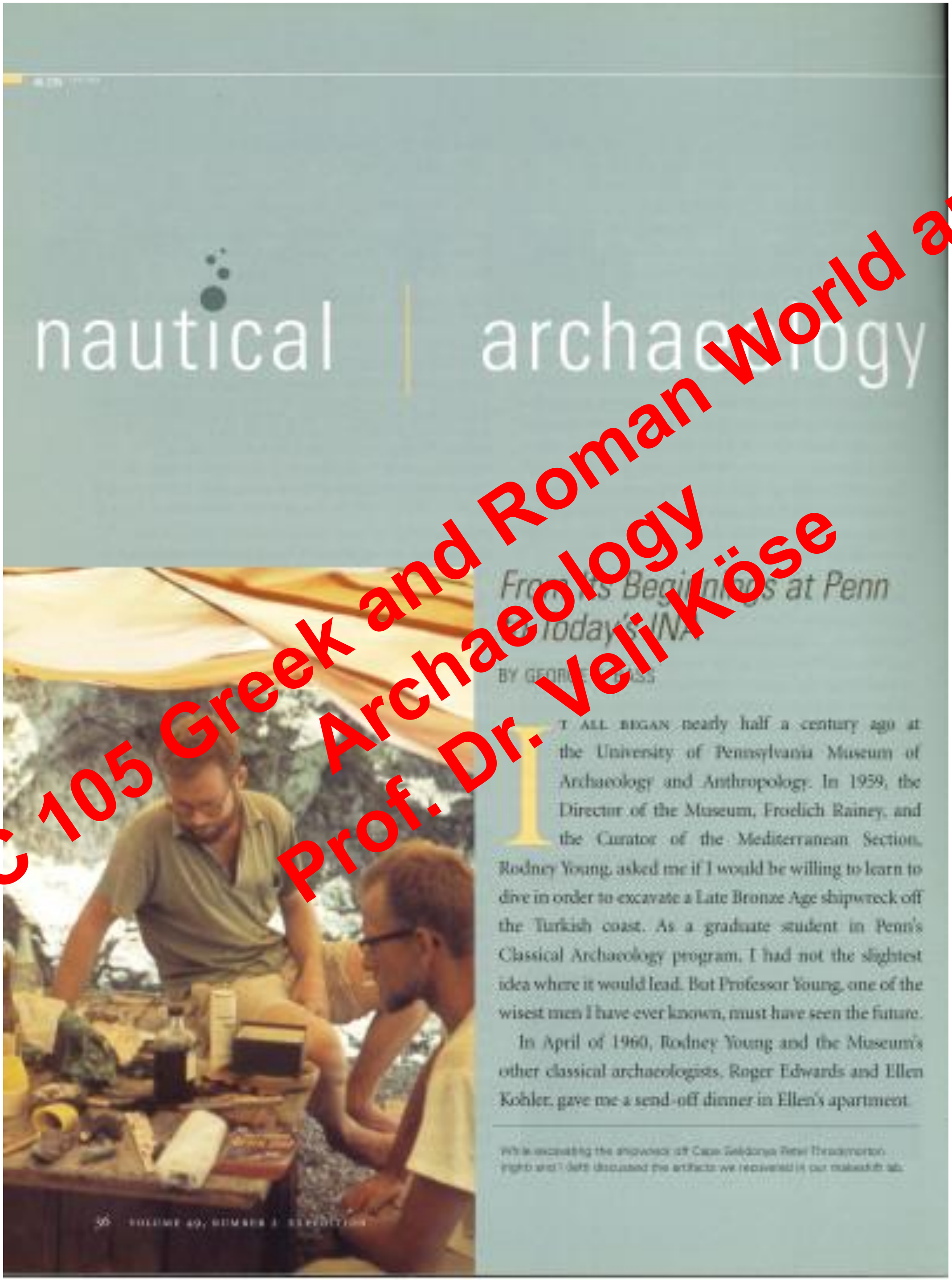
procedure adopted by another craftsman, the Egyptian Hag Ahmed Youssef, in his 14-year rebuilding of the dismantled ship of the pharaoh Cheops found at Giza, at 4500 years the oldest known ship in the world.

The next step in any assessment of a ship's construction techniques and handling capabilities is to build either a full-size or a scale replica, preferably one that can be tested on the water. Replicas based on excavated remains, such as the replica Viking *knarr* or cargo ship that sailed around the world in 1984–86, are more likely to produce scientifically accurate results than those built only from generalized artistic depictions, as in the case of replicas of the ships of Columbus. But the building of replicas based on depictions can still be immensely valuable. Until some British scholar-enthusiasts, led by J.F. Coates and J.S. Morrison, actually constructed and tested a replica of an ancient Greek trireme, or warship, in 1987, virtually nothing was known about the practical characteristics of this important seacraft of Classical antiquity.

Another contribution archaeology can make to seafaring studies is to demonstrate the presence of boats even where no ship remains or artistic depictions exist. The simple fact that people crossed into Australia at least 50,000 years ago – when that continent was cut off from the mainland, even if not by so great a distance as it is today – suggests that they had craft capable of covering 80 km (50 miles) or more. Similarly, the presence of obsidian from the Aegean islands on the Greek mainland 10,000 years ago shows that people at that time had no difficulty in sailing to and from the islands.

Plant and Animal Fibers

The making of containers, fabrics, and cords from skins, bark, and woven fibers probably dates back to the very earliest archaeological periods, but these textile materials rarely survive. However, as we saw in Chapter 2, they do often survive in very dry or wet conditions. In arid regions, such as Egypt or parts of the New World, such perishables have come down to us in some quantity, and the study of basketry and cordage there reveals complex and sophisticated



nautical | archaeology

From Its Beginnings at Penn to Today's INA

BY GEORGE F. BASS

IT ALL BEGAN nearly half a century ago at the University of Pennsylvania Museum of Archaeology and Anthropology. In 1959, the Director of the Museum, Froelich Rainey, and the Curator of the Mediterranean Section, Rodney Young, asked me if I would be willing to learn to dive in order to excavate a Late Bronze Age shipwreck off the Turkish coast. As a graduate student in Penn's Classical Archaeology program, I had not the slightest idea where it would lead. But Professor Young, one of the wisest men I have ever known, must have seen the future.

In April of 1960, Rodney Young and the Museum's other classical archaeologists, Roger Edwards and Ellen Kohler, gave me a send-off dinner in Ellen's apartment.

While excavating the shipwreck off Cape Gelidonya Peter Throckmorton (right) and I (left) discussed the artifacts we recovered in our makeshift lab.

"Do you think that if I work hard and really persevere I might one day become Secretary of the American School of Classical Studies at Athens?" I asked.

"Do this underwater thing right and you won't believe where it will take you," Rodney responded. How could he have known?

Since those early days, the discipline of nautical archaeology has become accepted and respected, and our Institute of Nautical Archaeology (INA)—devoted to the study of ships and their cargos—is active on four continents and has two endowed publication series. Now based at Texas A&M University, our teaching program has seven full-time faculty and draws students from around the world. Our beginnings, however, were much more modest.

THE EARLY YEARS AT PENN

Throughout the 1960s my team of fellow Penn students and I developed the techniques of underwater research and excavation during our summer field seasons off the coast of Turkey. These techniques included both the means by which we located underwater sites and how we recorded and excavated them (*Expedition* 3(2):2-11). Much of this work involved creativity and applying existing technology in new ways to solve underwater problems (*Expedition* 10(3):[illegible]). For example, we were the first to map the seabed using stereo photographs, the first to develop an underwater telephone booth to facilitate communication between the crew above and below water, the first to use sonar to locate an ancient shipwreck (*Expedition* 11(1):9-12), and the first to launch a commercially built research submersible in the United States—the *Asherah* (*Expedition* 7(2):19-30).

Michael [illegible] Katzev developed the first underwater telephone booth to facilitate communication between divers and those above water. It also served as an emergency refuge if something went wrong with our breathing apparatuses.

Frederick van Doorninck, a colleague since we were graduate students together at Penn, was the first person to recreate on paper an ancient hull from the thousands of wood fragments we mapped on the seabed. Shown here inspecting an anchor concretion, he is now an emeritus professor at Texas A&M University.

Our goal during this period was the complete excavation of shipwrecks and the recovery of their cargos. With such unique discoveries from beneath the waves we hoped to rewrite history, or at least gain a better understanding of ancient seafaring, ships, trade goods, and long-distance exchange networks. In 1960, we were the first to conduct the complete excavation of an ancient shipwreck on the seabed, a Bronze Age wreck just off Cape Gelidonya on Turkey's south coast. This was

Left, at the suggestion of James Pritchard, the Museum's Curator of Biblical Archaeology, our submersible was christened *Asherah* by my wife Ann after a Phoenician sea goddess. Middle, its delivery to the Museum drew the attention of curious onlookers. Right, after five years of underwater use the Museum sold it in 1969.

followed by excavating a Byzantine shipwreck near the Turkish island of Yassıada from 1961 to 1964 and then a nearby Roman shipwreck from 1967 to 1969.

Unfortunately, [illegible] work was not sufficient to impress the many classical archaeologists who scorned me and my fellow scuba-diving students as "those people who had fun diving and pulling amphoras out of the sea." As a result, after our 1969 campaign I decided to pack it all in and return to "real archaeology." Burned out from directing and funding what the head of the U. S. Navy's diving program had called "the largest diving operation in the world," while now teaching a full course load at Penn as an assistant professor of classical archaeology, I turned my sights to excavating on land again.

However, in 1971, as I troweled through the soil covering a Pre-classical site in southern Italy, I realized I had abandoned something with great archaeological potential. What could have been more important than watercraft to people in the past? Didn't ancient ships and boats deserve the same detailed study as pottery, sculpture, architecture, and coinage? And weren't ancient shipwrecks virtual time capsules of material culture, much like the eye-opening discoveries sealed in ancient tombs or found covered by sudden catastrophic events such as the volcanic eruption that buried Pompeii in Italy? Where else might we expect to find such detailed evidence about the everyday context of trade and exchange? Rather than walk away from underwater archaeology, perhaps I could solve my logistical problems by forming an institute devoted to the excavation of ancient shipwrecks.

Therefore, in 1972 I read a statement to the Penn Museum's Board of Managers requesting permission to form an institute devoted to underwater archaeology. I stated that I would raise all the necessary funds, including those for my own salary. Unfortunately, we disagreed on the details. Where I wanted to be a full-time administrator and researcher, like some of my colleagues at the Museum, the Board wanted me to remain on the teaching faculty. As a result, I gave the Museum a year's notice of my departure and began trying to raise funds to found an independent institute.

[illegible]

I soon discovered that no one who had supported my work for the Museum had any interest in sending funds directly to an institute consisting solely of stationery listing my home address. I kept at it, however, sending copies of my latest book, *A History of Seafaring Based on Underwater Arch[illegible]* to potential donors. Maybe the "First Alternate Selection" of the Book-of-the-Month Club would catch their [illegible]

I finally got a pledge, then another, [illegible] another, and at our first board meeting in Philadelphia in the spring of 19[illegible] we had a small but committed Board of Directors for what I had named the American Institute of Nautical Archaeology (AINA). As President, I would be paid $13,0[illegible] a year, while Michael [illegible]—who had set a new standard for our field by not only [illegible] but restoring a classical Greek ship off Cyprus at Kyrenia (*Expedition* 10(3):13-14, 11(2):55-59, [illegible] 14)—agreed to be Vice-President for $8,0[illegible] year. Initially we had no salary for our colleague John [illegible], who had a Master of Science in Oceanography, so he simply lived with me and my family in Philadelphia for several months until we came up with $5,000 a year for him.

Since none of us had life or health insurance, or any kind of retirement plan, Michael and Susan Katzev convinced us that our money would go farther if we moved to Cyprus, where they already had bought a house, and set up our headquarters there. So my wife Ann and I sold virtually everything we owned—our house, car, furniture, pictures off the wall, and the children's toys—everything but her baby grand piano and my archaeological library, which we shipped to Cyprus. Cynthia Eiseman, who had worked with us in Turkey while she was a Penn graduate student, agreed to serve as our Executive Director and tend the Institute's affairs in the States. She turned a spare bedroom in her Philadelphia house into an AINA office, and her husband James soon became our *pro bono* counsel.

At last, AINA had a home, but we knew of no more shipwrecks to excavate. So I left Ann in Nicosia, Cyprus, [illegible] and furnish a house, enroll our sons in English-speaking schools, and buy a car (she learned to [illegible] drove on the left in busy downtown traffic), [illegible] went to Turkey. With a few American and Turkish divers [illegible] lived on Turkish fishing boats for three months, sleeping on deck or in the fish hold, talking to sponge divers, chasing leads—some false and some good. We fo[illegible] shipwrecks in all. Eventually, we would excavate four of them along the southwest Turkish coast: [illegible] at Şeytan Deresi and Bozburun, and two inside Ser[illegible].

Our excavations at Serçe Limanı (1977–79) uncovered the remains of an 11th century AD Byzantine ship that had carried a 3-ton cargo of recycled glass—a million-piece jigsaw puzzle to reconstruct.

Bonito. But it was not until the end of the 1930s that the technique was introduced to Europe, and only in the 1960s that the use of statistical procedures and computers laid the foundations for the establishment of the long tree-ring chronologies now so fundamental to modern archaeology. Today dendrochronology has two distinct archaeological uses: (1) as a successful means of calibrating or correcting radiocarbon dates (see below); and (2) as an independent method of absolute dating in its own right.

Basis of Method. Most trees produce a ring of new wood each year and these circles of growth can easily be seen in a cross-section of the trunk of a felled tree. These rings are not of uniform thickness. In an individual tree, they will vary for two reasons. First, the rings become narrower with the increasing age of the tree. Second, the amount a tree grows each year is affected by fluctuations in climate. In arid regions, rainfall above the average one year will produce a particularly thick annual ring. In more temperate regions, sunlight and temperature may be more critical than rainfall in affecting a tree's growth. Here, a sharp cold spell in spring may produce a narrow growth ring.

Dendrochronologists measure and plot these rings and produce a diagram indicating the thickness of successive rings in an individual tree. Trees of the same species growing in the same area will generally show the same pattern of rings so that the growth sequence can be matched between successively older timbers to build up a chronology for an area. (It is not necessary to fell trees in order to study the ring sequence: a usable sample can be extracted by boring without harming the tree.) By matching sequences of rings from living trees of different ages as well as from old timber, dendrochronologists can produce a long, continuous sequence extending back hundreds, even thousands, of years from the present. Thus, when an ancient timber of the same species (e.g. Douglas fir in the American Southwest or oak in Europe) is found, it should be possible to match its tree-ring sequence of, say, 100 years with the appropriate 100-year length of the master sequence or chronology. In this way, the felling date for that piece of timber can usually be dated to within a year.

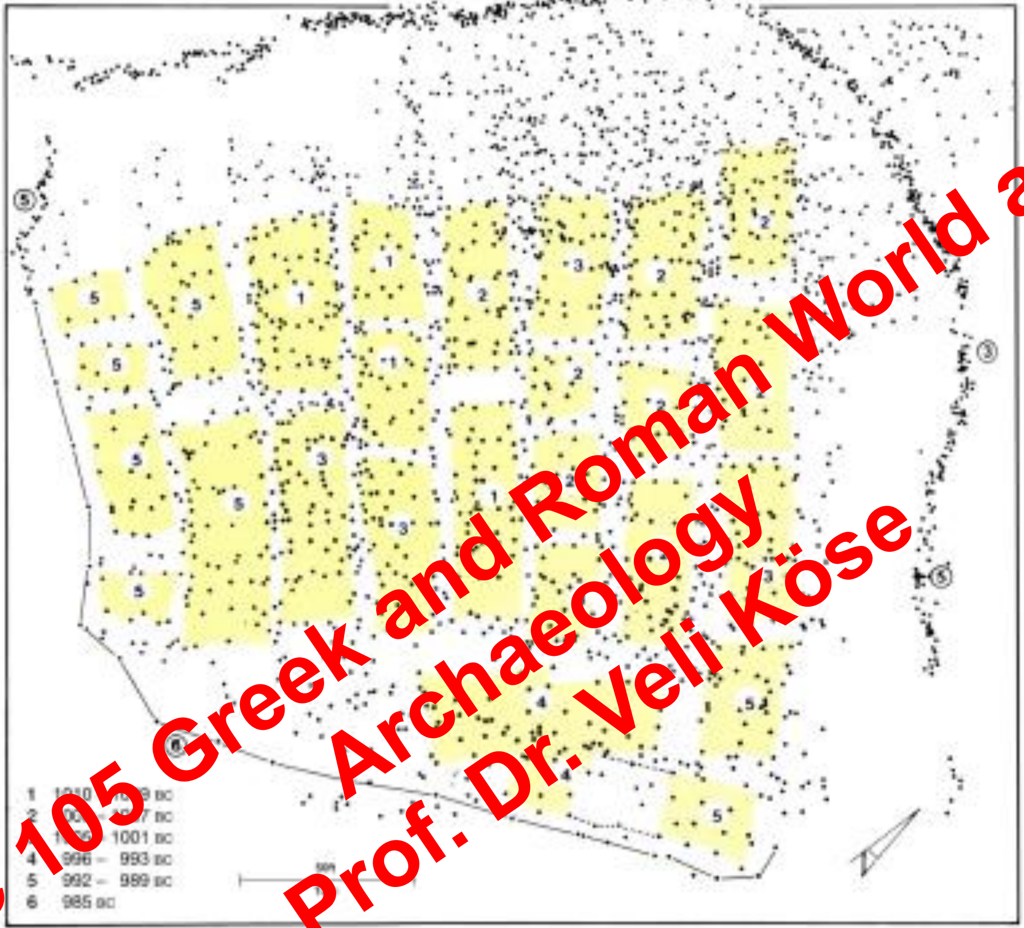
Applications: (1) The Long Master Sequences and Radiocarbon. Perhaps the greatest contribution so far of dendrochronology to archaeological dating has been the development of long tree-ring sequences, against which it has proved possible to check and calibrate radiocarbon dates. The pioneering research was done in Arizona on a remarkable species, the California bristlecone pine (*Pinus aristata*), some of which are up to 4900 years old – the oldest living things on earth. By matching samples from these living trees with rings from dead pines preserved in the region's arid environment, the scientists – led by E. Schulman and later C. Wesley Ferguson – built up an unbroken sequence back from the present as far as 6700 BC. Just how this sequence has been used for calibration work will be discussed in the section on radiocarbon below.

The research in the American Southwest has now been complemented by studies in Europe of tree-rings of oak, often well preserved in waterlogged deposits. Two separate oak sequences in Northern Ireland and western Germany both now stretch back unbroken into the distant past as far as *c.* 5300 BC in the Irish case and *c.* 8000 BC in the German. The scientists who did the work – Michael Baillie in Belfast, the late Bernd Becker in Stuttgart, and their colleagues – have also succeeded in matching the two separate sequences, thus creating a reliable central and west European absolute chronology against which to calibrate radiocarbon dates, as well as for use in direct tree-ring dating.

Applications: (2) Direct Tree-Ring Dating. Where people in the past used timber from a species, such as oak, that today forms one of the dendrochronological sequences, we can obtain an archaeologically useful absolute date by matching the preserved timber with part of the master sequence. This is now feasible in many parts of the world outside the tropics.

Results are particularly impressive in the *American Southwest*, where the technique is longest established and wood is well preserved. Here Pueblo Indians built their dwellings from trees such as the Douglas fir and piñon pine that have yielded excellent ring sequences. Dendrochronology has become the principal dating method for the Pueblo villages, the earliest dates for which belong to the 1st century BC, although the main period of building came a millennium later.

One brief example from the Southwest will serve to highlight the precision and implications of the method. In his pioneer work, A.E. Douglass had established that Betatakin, a cliff dwelling in northwest Arizona, dated from around AD 1270. Returning to the site in the 1960s, Jeffrey Dean collected 292 tree-ring samples and used them to document not just the founding of the settlement in AD 1267, but its expansion room by room, year by year until it reached a peak in the mid-1280s, before being abandoned shortly thereafter. Estimates of numbers of occupants per room also made it possible to calculate the rate of



Tree-ring dating of the late Bronze Age settlement of Cortaillod-Est, Switzerland, is remarkably precise. Founded in 1010 BC with a nucleus of four houses (phase 1), the village was enlarged four times, and a fence added in 985 BC.

expansion of Betatakin's population to a maximum of about 125 people. Dendrochronology can thus lead on to wider considerations beyond questions of dating.

In *central and western Europe*, the oak master sequences now allow the equally precise dating of the development of Neolithic and Bronze Age lake villages, such as Cortaillod Est in Switzerland. In the German Rhineland, close to the village of Kückhoven, recently discovered timbers from the wooden supporting frame of a well have provided three tree-ring dates of 5090 BC, 5067 BC, and 5055 BC. The timbers were associated with sherds of the *Linearbandkeramik* culture and thus provide an absolute date for the early practice of agriculture in western Europe. The earliest tree-ring date for the English Neolithic is from the Sweet Track in the Somerset Levels: a plank walkway constructed across a swamp during the winter of 3807/3806 BC, or shortly after (see box, pp. 314–15).

Sometimes local chronologies remain "floating" – their short-term sequences have not been tied into the main master sequences. In many parts of the world, however, master sequences are gradually being extended and floating chronologies fitted into them. In the Aegean area, for example, a master sequence is now available back to early medieval times (the Byzantine period), with an earlier floating sequence stretching over several centuries for the Classical period. In future, the link between them will no doubt be found. Considerable progress is being made toward establishing a long tree-ring chronology for Anatolia.

Limiting Factors. Unlike radiocarbon, dendrochronology is not a worldwide dating method because of two basic limitations:

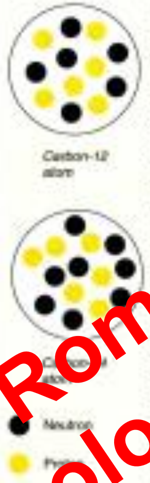
1 it applies only to trees in regions outside the tropics where pronounced differences between the seasons produce clearly defined annual rings;
2 for a direct tree-ring date it is restricted to wood from those species that (a) have yielded a master sequence back from the present and (b) people actually used in the past.

In addition, there are important questions of interpretation to consider. A tree-ring date refers to the date of felling of the tree. This is determined by matching the outermost rings (the sapwood) to a regional sequence. Where most or all of the sapwood is missing, the felling date cannot be identified. But even with an accurate felling date, the archaeologist has to make a judgment – based on context and formation processes – about how soon after felling the timber entered the archaeological deposit. Timbers may be older or younger than the structures into which they were finally incorporated, depending on whether they were reused from somewhere else, or used to make a repair in a long-established structure. As always, the best solution is to take multiple samples, and to check the evidence carefully on-site. Despite these complications, dendrochronology looks set to become the major dating technique alongside radiocarbon for the last 8000 years in temperate and arid lands.

RADIOACTIVE CLOCKS

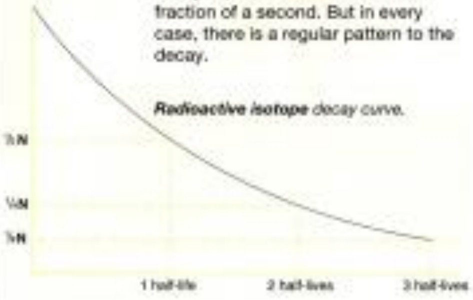
Many of the most important developments in absolute dating since World War II have come from the use of what one might call "radioactive clocks," based on that widespread and regular feature in the natural world, radioactive decay (see box). The best known of these methods is radiocarbon, today the main dating tool for the last 50,000 years or so. The main radioactive methods for periods before the timespan of radiocarbon are potassium-argon, uranium-series dating, and fission-track dating. Thermoluminescence

THE PRINCIPLES OF RADIOACTIVE DECAY



Like most elements occurring in nature, carbon exists in more than one isotopic form. It has three isotopes: ^{12}C, ^{13}C, and ^{14}C – the numbers correspond to the atomic weights of these isotopes. In any sample of carbon 98.9 percent of atoms are of ^{12}C type and have six protons and six neutrons in the nucleus, and 1.1 percent are of the ^{13}C type with six protons and seven neutrons. Only one atom in a million million of atoms of carbon will be that of the isotope ^{14}C with eight neutrons in the nucleus. This isotope of carbon is produced in the upper atmosphere by cosmic rays bombarding nitrogen (^{14}N) and it contains an excess of neutrons, making it unstable. It decays by the emission of weak beta radiation back to its precursor isotope of nitrogen – ^{14}N – with seven protons and seven neutrons in a nucleus. Like all types of radioactive decay the process takes place at a constant rate, independent of all environmental conditions.

The time taken for half of the atoms of a radioactive isotope to decay is called its half-life. In other words, after one half-life, there will be half of the atoms left; after two half-lives, one-quarter of the original quantity of isotope remains, and so on. In the case of ^{14}C, the half-life is now agreed to be 5730 years. For ^{238}U, it is 4500 million years. For certain other isotopes, the half-life is a minute fraction of a second. But in every case, there is a regular pattern to the decay.



Radioactive isotope decay curve.

frequently, for short or long periods, irregularly or seasonally (season of occupation can sometimes be deduced from plant and animal evidence as well). A long-term settlement is likely to provide more representative food remains than a specialized camp or kill site. Ideally, however, archaeologists should sample remains from a variety of contexts or sites before making judgments about diet.

WHAT CAN PLANT FOODS TELL US ABOUT DIET?

Macrobotanical Remains

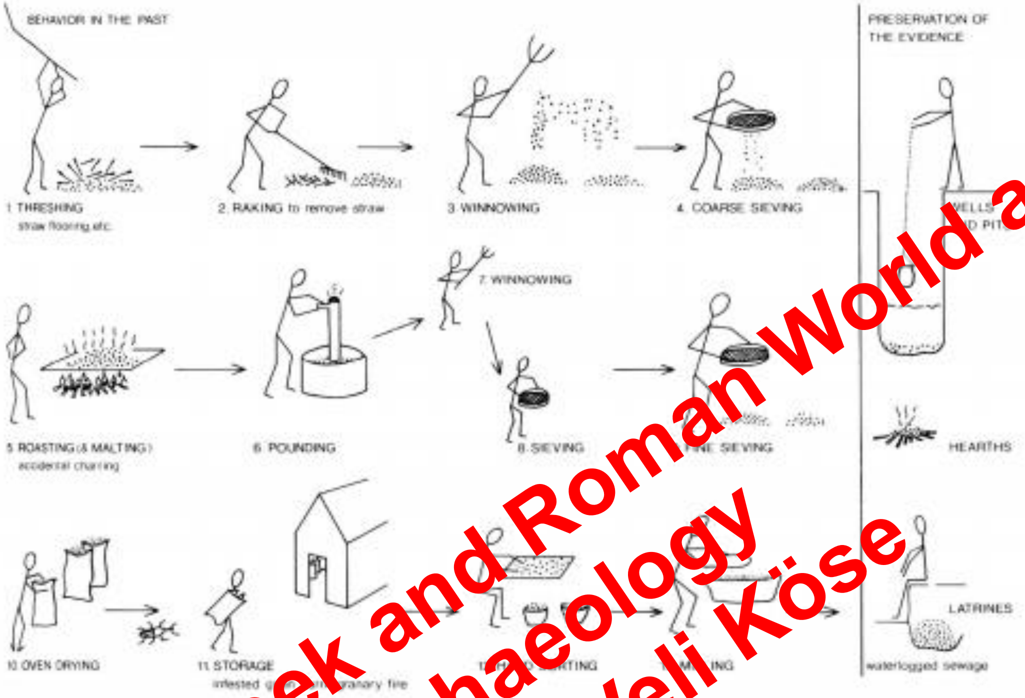
The vast majority of plant evidence that reaches the archaeologist is in the form of macrobotanical remains, usually desiccated, waterlogged, or preserved by charring. Such remains can also survive by being partly or wholly replaced by minerals percolating through sediment, a process that tends to occur in places like latrine pits with high concentrations of salts. Charred remains are collected by flotation (Chapter 6), waterlogged remains by wet sieving, desiccated by dry sieving, and mineralized by wet or dry sieving according to context. It is the absence of moisture or fresh air that leads to good preservation by preventing the activity of putrefactive microbes. Plant remains preserved in several different ways can sometimes be encountered within the same site, but in most parts of the world charring is the principal or only cause of preservation on habitation sites.

Occasionally, a single sample on a site will yield very large amounts of material: over 27 kg (60 lb) of charred barley, wheat, and other plants came from one storage pit on a Bronze Age farm at Black Patch, southern England, for example. This can sometimes give clues to the relative importance of different cereals and legumes and weed flora, but the sample nevertheless simply reflects a moment in time. What the archaeologist really needs is a larger number of samples (each of preferably more than 100 grains) from a single period on the site, and, if possible, from a range of types of deposit, in order to obtain reliable information about what species were exploited, their importance, and their uses during the period of time in question.

Having obtained sufficient samples, one needs to quantify the plant remains. This can be done by weight, by number of remains, or by some equivalent of the Minimum Number of Individuals technique used for bones (see below). Some scholars have suggested dispensing with percentages of plant remains in a site, and simply placing them in apparent order of abundance. But numerical frequency can be misleading, as was shown by the British archaeobotanist Jane Renfrew in her study of the material from the Neolithic settlement of Sitagroi, Greece. She pointed out that the most abundant plant in the sample may have been preserved by chance (such as an accident in the course of baking) and thus be over-represented. Similarly, species that produce seeds or grains in abundance may appear to have an exaggerated importance in the archaeological record. At Sitagroi, 19,000 seeds of *Polygonum aviculare* or knotgrass barely filled a thimble; and it makes little sense to equate an acorn with a cereal grain or a vetch seed. Quite apart from size differences, they make very different contributions to a diet.

Interpreting the Context and the Remains. It is crucial for the archaeologist or specialist to try to understand the archaeological context of a plant sample. In the past attention used to be focused primarily on the botanical history of the plants themselves, their morphology, place of origin, and evolution. Now, however, archaeologists also want to know more about the human use of plants in hunting and gathering economies and in agriculture – which plants were important in the diet, and how they were gathered or grown, processed, stored, and cooked. This means understanding the different stages of traditional plant processing; recognizing the effect different processes have on the remains; and identifying the different contexts in the archaeological record. In many cases it is the plant remains that reveal the function of the location where they are found, and thus the nature of the context, rather than vice versa.

In a farming economy, there are many different stages of plant processing. For example, cereals have to be threshed, winnowed, and cleaned before consumption, in order to separate the grain from the chaff, straw, and weeds; but seed corn also has to be stored for the next year's crop; and food grain might also be stored unthreshed in order to get the harvested crop out of the rain, and would then be threshed only when needed. Many of these activities are well documented in our recent agricultural past, before mechanization took over, and they are still observable ethnoarchaeologically in cultures with differing degrees of efficiency and technological capability. In addition, experiments have been carried out in crop processing. From these observations it is known that



Cereal crop processing: waste products from many of these stages may survive as charred or waterlogged remains.

certain activities leave characteristic residues with which archaeological samples can be compared, whether these are from ovens, living floors, latrines, or storage pits.

There are two main approaches to crop remains. Most archaeobotanists now use "external evidence," and proceed from ethnographic observation of, or experimentation with, plant-processing activities to an examination of the archaeological remains and contexts. In some cases, however, the archaeologist uses an "internal analysis," focusing almost exclusively on the archaeological data: for example, in his study of the plant material from the Bulgarian Neolithic site of Chevdar (6th millennium BC), the British archaeologist Robin Dennell noted that samples from the ovens had been processed, as one might expect, and were being either dried for storage or cooked when they were accidentally charred. Samples from floors, on the other hand, contained a higher percentage of weed seeds, but no spikelets (small, spike-shaped subdivisions of an ear of grain), suggesting that they were still in the process of being prepared, but had already been threshed and winnowed. The number and variety of weed species present can give clues to the effectiveness of the processing. Most samples show some mixing of different crops, and archaeologists need to bear this in mind when interpreting the data – indeed, the crops may have been mixed at the sowing stage in a fail-safe strategy of growing everything together in the hope that at least something would ripen.

In short, it is desirable, as mentioned earlier, to take samples from as wide an area as possible in the site, and from a variety of contexts. A species that dominates in a number of samples and contexts may be reckoned to have been important in the economy. Change through time can be assessed accurately only by comparing samples from similar contexts and processing stages, because the plant remains recovered in a site are not random in composition, and may not necessarily reflect the full crop economy. This is particularly true of charred samples, for many important plant foods may never undergo charring. Hulled wheats such as emmer, for example, which require parching to free their grains, are far more likely to be charred than are free-threshing varieties such as bread wheat. Plants that are boiled, eaten raw, or used for juices and to make drinks may never undergo charring, and will therefore be underrepresented or totally absent in an assemblage. If the charring is caused by some accident, the sample may not even be representative of that season's harvest, let alone the site's economy. This again emphasizes the importance of obtaining a variety of samples.

Reconstruction of the crop system that produced the samples is particularly challenging, since entirely different crop systems using the same resources can produce very similar pictures in the archaeological record. Furthermore, it is likely that a great deal of plant refuse was left in the field, used as fuel, or fed to animals. Thus we may never know for certain, without literary evidence, precisely what system of fallow or crop rotation was employed at a particular site. But information about questions of this sort has been obtained from experimental work at Butser Farm in southern England (and similar establishments in Denmark, the Netherlands, Germany, and France), where different agricultural techniques are tried out: cultivation with and without manure, various alternations of crops and fallow, etc. This long-term work will take years to provide full results, but already short-term experiments have produced valuable data on crop yields, different types of storage pits, use of sickles, and so on.

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These can also be of help in the reconstruction of diet. Some of the minute particles of silica called *phytoliths* (Chapter 6) are specific to certain parts of a plant (to the root, stem, or flower), and thus their presence may provide clues to the particular harvesting or threshing technique employed on the species. As will be seen below, phytoliths can also help in differentiating wild from domestic species.

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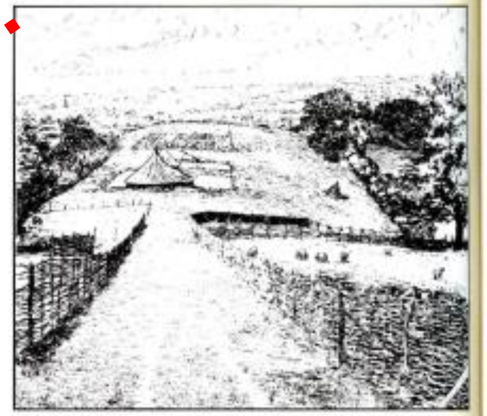


Artist's impression *of Butser Ancient Farm. Hurdle fences in the foreground enclose sheep pens. Beyond lie the two round houses of the farm itself.*

centuries AD) yielded 1440 kg (1.4 tons) – the annual yield cannot yet be estimated since we do not know for how long the fields were in use, and it is not yet possible to compare these figures with modern yields.

In addition, phytoliths found adhering to the edges of stone tools (see below) may provide information about the plants on which the tools were used, although it must be remembered that such plants may not have figured in the diet.

Pollen grains often survive in coprolites, but most of them were probably inhaled rather than consumed, and thus they merely add to the picture of the contemporary environment, as shown in Chapter 6.

Chemical Residues in Plant Remains

Various chemicals survive in plant remains themselves which provide an alternative basis for their identification. These compounds include proteins, fatty lipids, and even DNA. The lipids analyzed using infrared spectroscopy, gas liquid chromatography, and gas chromatography mass spectrometry, have so far proved the most useful for distinguishing different cereal and legume species, but always in combination with morphological criteria. DNA offers the prospect of eventually resolving identification at an even more detailed level and of perhaps tracing family trees of the plants and patterns of trade in plant products.

An almost perfect grain impression: two-row barley (×4) from a brick used about AD 800 in the building of a weir in the Nahrwan Canal east of Baghdad, Iraq.

Plant Impressions

Impressions of plant remains are quite common in fired clay (Chapter 6), and do at least prove that the species in question was present at the spot where the clay was worked. Such impressions, however, should not be taken as representative of economy or diet, since they constitute a very skewed sample and only seeds or grains of medium size tend to leave imprints. One has to be particularly careful with impressions on potsherds, because pottery can be discarded far from its point of manufacture, and in any case many pots were deliberately decorated with grain impressions, thus perhaps overemphasizing the importance of a species. Imprints in other objects can be more helpful, such as those in clay bricks from the 3rd millennium BC in Abu Dhabi on the Persian Gulf which represent not only two-row barley but also one of the oldest known traces of the cereal crop sorghum.

Turning now from such "passive" evidence, what can be learned from objects that were actually applied to plant materials?

Tools and Other Equipment Used in Plant Processing

Tools can prove or at least suggest that plants were processed at a site, and on rare occasions may indicate the species concerned, and the use that was made of it. In some parts of the world, the mere presence of pottery, sickles, or stone grinders in the archaeological record is taken to prove the existence of cereal farming and settled agricultural life. But in themselves they are inadequate indicators of such features, and require supporting evidence such as remains of domesticated plants. Sickles, for example, may have been used to cut reeds or wild grasses (and a polish or "sickle-sheen" on them is sometimes seen as proof of such a use), while grinders can be employed to process wild plants, meat, cartilage, salt, or pigments. Objects from more recent cultures often have clearer functions – for example, the bread ovens (containing round loaves) at the bakery of Modestus in Pompeii, the flour-grinding mills and wine-presses of the same city, or the great olive-crushers in a Hellenistic house at Praisos, Crete.

Analysis of Plant Residues on Artifacts

Since most tools are fairly mute evidence in themselves, it follows that we can learn far more about

PALEOETHNOBOTANY: A CASE STUDY

The recovery and identification of plant remains from archaeological contexts are merely the first steps in a wide-ranging series of research issues that make up paleoethnobotany, also known as archaeobotany.

Such issues encompass not only the reconstruction of past environments (Chapter 6) and economies, but also the origins and spread of agriculture (see box, pp. 280–81) and human use of – and impact on – plant communities in the broadest sense. In addition to studying the plant remains themselves, archaeobotanists can learn a great deal from ethnoarchaeological observation among human groups still practicing traditional methods of plant use or farming, and from assessing the natural potential of the plants in the relevant ecological settings.

A good way to gain an insight into these methods is to look in detail at a recent successful case study.

Wadi Kubbaniya

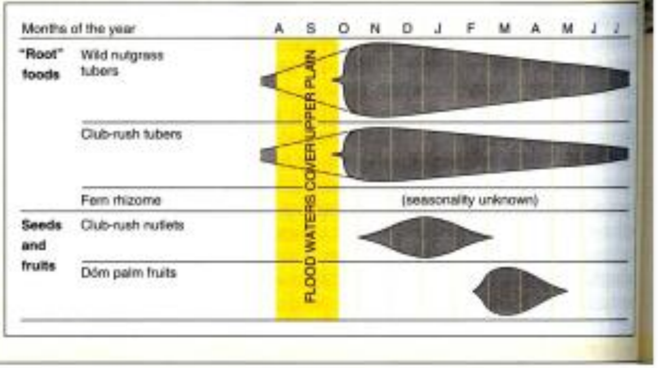
Four sites dating to between 19,000 and 17,000 years ago were excavated by Fred Wendorf and his associates at this locality northwest of Aswan in Upper Egypt. The sites have produced the most diverse assemblage of food plant remains ever recovered from any Paleolithic excavation in the Old World. The material, which owes its good preservation to rapid burial by sand and the area's great aridity, is concentrated around hearths of wood charcoal, and is dominated by charred fragments of soft vegetable foods, a category of plant that normally has very low archaeological visibility. Flotation (Chapter 6) proved useless for this material, because the fragile, dry remains disintegrated in water; instead, dry sieving had to be employed. Small roasted seeds were also found in what appear to be the feces of human infants.

Analysis of the charred remains by Gordon Hillman and his colleagues at London's Institute of Archaeology has led to the identification of over 20 different types of food-plant brought into the sites, indicating that the occupants' menu was markedly diverse. By far the most abundant food-plants were tubers of wild nutgrass (*Cyperus rotundus*). Other species included different tubers, as well as club-rushes, dóm palm fruits, and various seeds. A study was carried out to ascertain what contribution the nutgrass tubers were likely to have made to the Paleolithic diet.

Investigation of the plant's modern locations, its yields, and its nutritional value suggested that literally tons of tubers could have been obtained easily each year by means of digging sticks. Annual harvesting stimulates the rapid production of abundant young tubers. Since prehistoric people would certainly have noticed this phenomenon, it is by no means impossible that they evolved a system of management, or proto-horticulture, to bring it about consciously.

Ethnographic evidence was available from further afield. Among farming

Wild nutgrass *(Cyperus rotundus). Sketch of the living plant, with a few of its edible tubers. (Above left) One of the charred tubers found at Site E-78-3, during excavations at Wadi Kubbaniya.*



Possible seasons *of exploitation of major plant foods at Late Paleolithic Wadi Kubbaniya – assuming no storage of food. The varying widths of the bands indicate seasonal variations in the availability (and likely exploitation) of each plant, based on modern growth patterns and known preferences of modern hunter-gatherers. For two months floodwaters probably covered most of the plants, making them inaccessible during that time.*

populations in West Africa, Malaysia, and India nutgrass tubers have become a famine food, eaten when crops fail. In some desert areas of Australia, Aborigine hunter-gatherers exploit the tubers as a staple resource. As long as they are cooked to make them digestible and non-toxic, they can be the principal source of calories during months when they are available. Ethnographic evidence also shows that tubers are preferred over seeds because they involve less work in processing.

The next step at Wadi Kubbaniya was to use the plant evidence to study whether occupation at the site was seasonal or year-round. Nutgrass tubers were probably available for at least half the year; but they are at their most palatable during the period of active growth, from October to January. Wadi Kubbaniya has no evidence of storage which might have prolonged the tubers' availability, but their growth period together with that of the other species identified at the site would have ensured a food supply for the full year. This does not prove that occupation was not seasonal, but shows that year-round occupation was feasible on the basis of plant resources alone.

Finally, it should be noted that animal-product resources were also in evidence at the site (e.g. fish bones, molluscs), and that many plants prominent in the area today but unrepresented in the remains could have been of importance (e.g. additional palm fruits, rhizomes, leaves, and roots). What is clear, however, is that nutgrass tubers were the dominant resource – the only plant present in all levels at all four sites – and therefore were probably a dietary staple, if not *the* staple resource.

One of the four Wadi Kubbaniya sites (designated E-78-3) under excavation.

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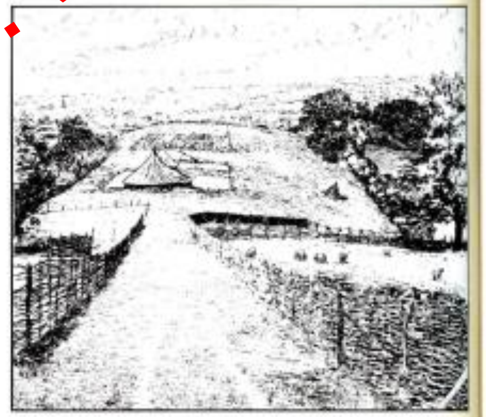


***Artist's impression** of Butser Ancient Farm. Hurdle fences in the foreground enclose sheep pens. Beyond lie the two round houses of the farm itself.*

Replica Iron Age round house at Butser with its thatched roof.

been learned about the quantities of timber required (more than 200 trees in the case of a large house), and about the impressive strength of these structures, whose thatched roofs and walls of rods woven between upright stakes have withstood hurricane-force winds and torrential rain.

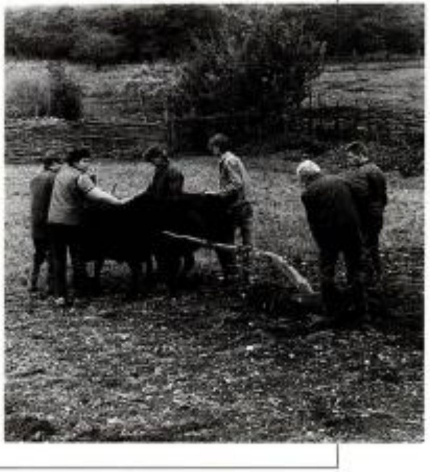
The farm is intended to be a long-term project, and results so far are only preliminary. But it has already been established that wheat yields are far beyond what was considered likely for the Iron Age even in drought years, and this may cause a radical revision of population estimates. In addition, the primitive wheats used, such as einkorn (*Triticum monococcum*), emmer (*Tr. dicoccum*), and spelt (*Tr. spelta*), were found to produce twice as much protein as modern wheats, and to thrive in weed-choked fields without modern fertilizers.

The farm's several fields have been tilled in different ways, such as by an ard (a copy of one found in a Danish peat bog) which stirs up the topsoil but does not invert it. Various systems of crop rotation and fallow are being tested, both with and without manure, and with spring and winter sowing. Also successfully tried out has been a replica of a "vallus," a kind of reaping machine dating to AD 20 that comprises a two-wheeled vehicle pulled by a draft animal and guided by one person.

Peter Reynolds' team have conducted experiments to assess the effects on grain when stored in different types of pit. One conclusion, supported by ethnographic observations of storage pits in Africa and elsewhere, is that if the seal is impermeable, unparched grain can be stored for long periods without decaying and the germinability maintained.

As for animals, Soay sheep – a type that has remained virtually unaltered for 2000 years – were brought from some Scottish islands. They have proved difficult to keep because of their ability to leap fences. Long-legged Dexter cattle, similar in size and power to the extinct Celtic Shorthorn, have also been installed, and two of them trained for use in traction (pulling the ard).

The Butser Project, which is open to the public, gives us a fascinating glimpse of the Iron Age brought to life, a working interpretation of the past.



***Dexter cattle** being trained as traction animals to pull the Iron Age ard or plow. After training, two men are sufficient, one to guide the cattle and another the ard.*