THE MICROSCOPE • Vol 58:1, pp 3-18 (2010)

# Forensic Applications of Foraminifera[1]

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## KEYWORDS

Forensic geology, forensic geoscience, forensic soil analysis, microfossils, foraminifera

## ABSTRACT

Foraminifera are single-celled protozoa whose tests are found in great abundance on beaches and as fossils in marine limestones. A general introduction to foraminifera and their tests is followed by a discussion of their potential applications in forensic science. Several case examples are described where foraminifera were valuable in solving forensic problems.

## INTRODUCTION

### Classification

Foraminifera are classified under the Kingdom Protista and Phylum Sarcomastigophora. They are in the Subphylum Sarcodina with amoebas and other unicellular specks of cytoplasm. Foraminifera have this taxonomy because they are single-celled protozoa with no tissues or organs. Despite being unicellular, they can reach sizes of up to 18 centimeters, although the vast majority are smaller than one millimeter (1). They are in the Class Granuloreticulosa due to their granuloreticulose pseudopodia (thread-like extensions of ectoplasm), which they use for locomotion and to collect food. They are in the Subclass Rhizopoda and are their own Order: the Foraminiferida.

### The Test

Foraminifera generally form protective shells, called "tests," either of secreted material or agglutinated foreign matter. Their name comes from the term foramina, meaning "openings," after the openings between adjacent chambers in their tests. They exhibit enormous complexity, with different areas of the cell performing specialized functions. Foraminifera that secrete their tests produce complex and varied structures. Those with agglutinated tests are capable of selecting particles to construct their tests based on composition, size, shape, density and even color (1, 2). Foraminifera are classified based on four features of their tests as discussed below.

#### *Wall Composition and Structure*

The test wall composition and structure are the most important features used in the identification and classification of foraminifera. Tests may be composed of excreted organic matter, agglutinated foreign material or excreted mineral material (calcium carbonate or silica). The majority of foraminifera excrete calcium carbonate to form their tests. Chamber walls may demonstrate a variety of architecture, including single calcite crystals, minute randomly oriented calcite grains, radially oriented calcite crystals and complex layered structures (1).

#### *Number, Size and Arrangement of Chambers*

The number, size and arrangement of chambers are used to further classify foraminifera. Tests may be

[1]Presented at Inter/Micro 2009, Chicago.
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Figure 1

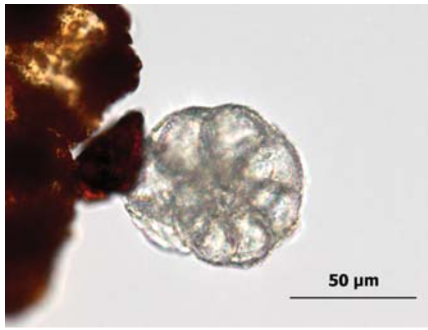


Figure 2

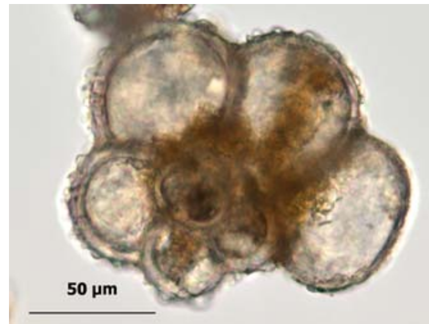


Figure 3

Figure 4

Figure 5

Figures 1-5. Foraminifer specimens shown in transmitted plane-polarized light with a mounting medium of 1.540. Figure 1, a unilocular (single chambered) test. Figure 2, a planispiral test and wedge-shaped chambers. Figure 3, a trochospiral test and globular chambers. Figure 4, a biserial test and globular chambers. Figure 5, a test that begins with planispiral arrangement of chambers and becomes biserial in later growth.

composed of a single chamber (**Figure 1**) or of multiple chambers. Tests containing multiple chambers may have their chambers organized in a spiral with all chambers in one plane (planispiral, **Figure 2**) or with chambers spiraling out of a plane like a helix (trochospiral, **Figure 3**). Alternatively, tests may have chambers that are attached end-to-end in rows of one (uniserial), two (biserial, **Figure 4**), three (triserial) or more. Some forms combine two or more of these arrangements, for example, beginning as a planispiral form and becoming biserial in later growth (**Figure 5**). The shape of the chambers present in foraminifera tests varies as well, including chambers that are wedge-shaped (**Figure 2**), globular (**Figure 4**), tubular and lunate (1, 3).

*The Aperture*

Foraminifera tests typically have at least one aperture in their terminal chamber. This aperture is the opening through which materials are exchanged between the external environment and the interior of the cell. Tests may contain one or more apertures. The number of apertures, their location, shape and structures formed on the aperture — such as teeth, lips or cover plates — are used to further classify the test (1, 2, 3). Several examples of apertures are shown in **Figures 6-8**.

*Surface Ornamentation*

The final feature used to classify foraminifera is ornamentation on the external surface of the test. Tests may have a smooth surface (**Figure 9**), or they may have a variety of textures on their surface, including striations (**Figure 10**), raised bumps (**Figure 11**), depressed dimples (**Figure 12**), raised lines (keels), spines and more (1).

## POTENTIAL FORENSIC APPLICATIONS

There are several reasons why foraminifera have the potential to be useful as forensic evidence. The first is their wide distribution. As much as one-sixth of the Earth's surface is covered by microfossil-bearing sediment, much of which contains foraminifera (1). Soil formed on these rocks and detritus near outcrops are likely to contain fossil foraminifera. Marine limestone is used in a variety of construction and industrial applications, making the distribution of foraminifera in

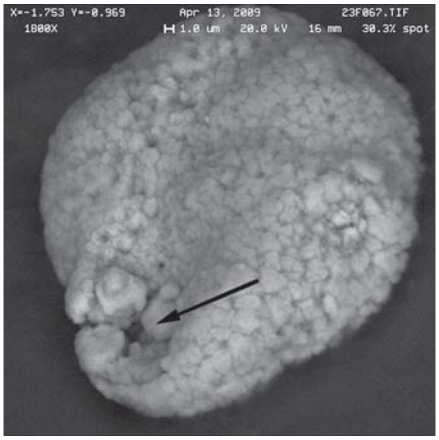


Figure 6

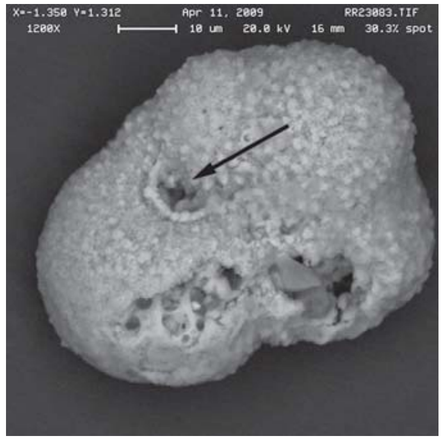


Figure 7

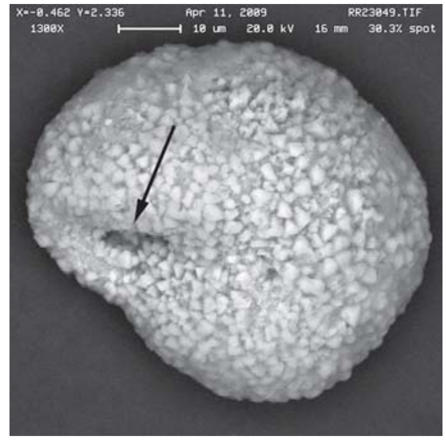


Figure 8

Figures 6-8. Arrows indicate the visible apertures of foraminifer specimens shown by scanning electron microscopy in back-scattered electron imaging mode.

the environment greater than the natural distribution of fossil-bearing rocks. Living species of foraminifera occur in marine environments including beaches, marshes and tidal pools.

The second reason that foraminifera have the potential to be useful forensic evidence is their small size. The tests of most foraminifera are smaller than 1 millimeter in size and some are only tens of micrometers, making them likely to be transferred during contact between an individual and a soil or sand. Once transferred, their small size makes them likely to persist on clothing, shoes, tires, etc. as potential evidence. Together, their widespread distribution and small size suggest that foraminifera may occur as evidence fairly frequently. The author has encountered fossil foraminifera in samples associated with a variety of evidence items, including on clothing and footwear, inside sealed electronic devices, and stuck in plastic explosive.

The third reason foraminifera have the potential to be useful as evidence is the great number of described taxa (tens of thousands of species) and the fact that the life of most species is fairly brief in geologic terms (often 5 to 15 million years). Because of the large number of taxa, if two samples are determined to have similar taxa present in similar relative abundances, this would be very compelling evidence that the two samples came from the same sedimentary deposit. The state of preservation of the taxa can be an additional feature for comparing two or more samples. Due to the fact that many species are restricted to short time frames in the geologic record, foraminifera offer great potential for investigative purposes as well as for comparison. The taxa identified in a sample can be used to constrain the age of the source sediment and assist in locating the geologic formation from which a sample originated.

## FORENSIC CASE EXAMPLES

The use of foraminifera in forensic geoscience is not a novel concept. They have been discussed as potential evidence in several books on forensic geology (4, 5). Despite this fact, there are very few published examples of their use in forensic science. An Internet search including the terms "diatoms" and "forensic" turns up numerous relevant Web sites and a variety of articles and books on the topic. However, a similar search using the terms "foraminifera" and "forensic" produces virtually nothing relevant. Published case examples are sparse, and correspondence with leading forensic geologists produced very little in addition to the published examples. The totality of published cases on forensic use of foraminifera appears to be one fictional story, one military intelligence investigation and two criminal investigations. There are also a small number of unpublished criminal cases that utilized foraminifera. Several of these cases are summarized below.

### <u>The Green Check Jacket</u>

The use of foraminifera in criminal investigation was proposed as early as 1925. In a fictional story by R. Austin Freeman titled "The Green Check Jacket," a man disappeared shortly after telling his attorney he had prepared a new will. The victim was last seen buying a length of rope with a man wearing a green check jacket. Later that evening a man wearing a similar jacket was seen entering the victim's home, and the jacket was

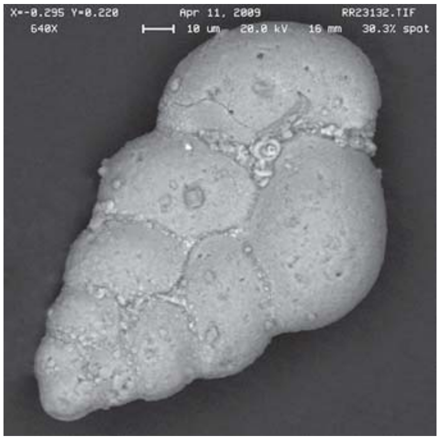


Figure 9

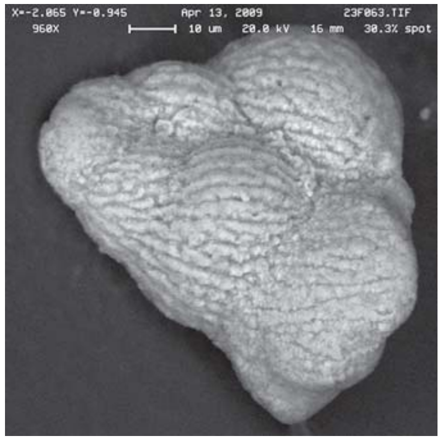


Figure 10

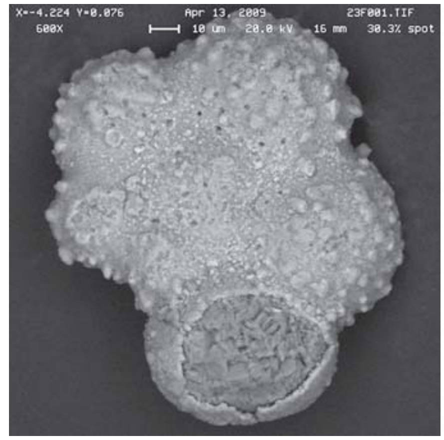


Figure 11

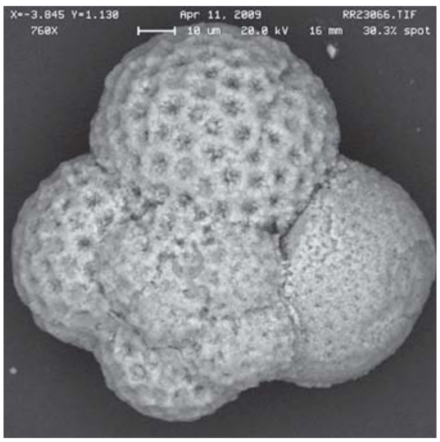


Figure 12

Figures 9-12. Foraminifer tests shown by scanning electron microscopy in back-scattered electron imaging mode. Figure 9, with smooth test walls. Figure 10, with coarse striations on its exterior surface. Figure 11, with raised bumps and small pores on its exterior surface. Figure 12, with depressed areas on its exterior surface.

later found in the victim's home. The jacket was dusty and its pockets contained fragments of chalk. Foraminifera were isolated from the chalk and their species identified by Dr. Thorndyke (the detective protagonist in the story). The victim was known to be interested in ancient chalk mines, and Dr. Thorndyke suspected that the rope had been purchased for climbing down one of these mines. He used the identified foraminifera species along with local geologic maps to narrow down the possible location of the mine. Dr. Thorndyke was able to locate the mine and the victim's body, leading to the eventual capture of the murderer (6).

**World War II Japanese Balloon Bombs**

During World War II the Japanese developed sophisticated balloon bombs armed with antipersonnel and incendiary explosive devices. These bombs were released into jet stream winds at high altitudes and were designed to travel across the Pacific Ocean and detonate in the continental United States. They used a gas-release valve and sand-filled ballast bags to maintain altitude during flight. The goals of the balloon bombing were to inspire terror in the American public and ignite large fires in the dense forests of the northwestern U.S. Approximately 9,000 of these bombs were launched between November 1944 and March 1945. There were 285 balloon bombs that were confirmed to have successfully detonated in the United States, and it is estimated that another 700 probably made the journey as well but were not observed. While the balloon bombs largely landed in unpopulated areas and caused minimal damage, one was discovered by a minister's wife and five children, who accidentally detonated it; all six were killed. They were the only U.S. mainland casualties of enemy fire in World War II.

A number of ballast bags from unexploded balloons were recovered and analyzed by the Military Geology Unit of the U.S. Geological Survey. The sand had unusual mineralogy, with a concentration of heavy minerals (primarily of volcanic origin) rarely encountered in beach sands. The mineralogy eliminated North America as a possible source of the sand. In addition to the unusual minerals, there were a number of microfossils present including diatoms and foraminifera. Similar specimens of diatoms and foraminifera had been described in Japanese geologic papers from beaches north of Tokyo. The Military Geology Unit used all of the available data to propose two possible launch sites. One of the potential launch sites proposed was in fact one of three sites being used by the Japanese to launch the balloons, namely the beach near Ichinomiya. The Japanese ended the balloon bomb assault due to doubts about their effectiveness and U.S. bombing raids that disrupted manufacture and supply of the balloon bomb materials (7, 8).

**Aldo Moro Kidnapping and Murder**

Italian Prime Minister Aldo Moro was ambushed and kidnapped on March 16, 1978. He was later killed and left in the trunk of a car in the center of Rome. During the autopsy, a small amount of sand was found in his trouser cuffs and on his shoes. Additional material was collected from the car in which Moro was found. The evidence was grouped into five categories: beach sand, volcanic soil, vegetable and animal fragments, asphalt, and anthropogenic material. The mineralogy of the sand was useful for constraining the provenance of the sample based on geologic maps of the region. The sand was also observed to contain numerous foraminifera (at least 18 different species) with both recent and fossil species represented. The recent species helped to constrain the type of marine environment from which the beach sand was derived, and the fossil species indicated that there must be Upper-Middle Miocene formations outcropping near the beach.

Based on the totality of the data, the sample was determined to be consistent with beach sand from close to the wind and water line along the Tyrrhenian coast near Rome. All accesses to the beach in this region (approximately 150 km of shoreline) were searched, and reference sand samples were collected from 92 beach access sites. Twenty-two samples were eliminated as possibilities after examination by stereomicroscopy. The remaining 70 samples were prepared and analyzed in the same manner as the questioned samples. The results of the comparisons confined the possible source area to a stretch of beach roughly 11 kilometers long just north of the Tiber River. On this stretch of beach there were only a few roads providing access to the beach, suggesting the victim had entered the beach from one of these roads shortly before his death. There was never any independent confirmation of the source of the sand, so it remains unknown whether the source was accurately determined or not. However, the foraminifera present in the sample were important in constraining the possible source of the sand during the investigation (9).

**FBI Case Examples**

The FBI Laboratory has encountered foraminifera in cases and used them primarily for comparative purposes. Microfossils (possibly including foraminifera) have also been used by the FBI to determine provenance. One specific example is a case worked by FBI Special Agent Ronald Rawalt. The case involved a missing Harrisburg, PA, police officer. After the officer failed to report to work, the officer's personal vehicle was found in Virginia with blood in the trunk and conspicuous mud in one wheel well. Rawalt analyzed the mud and found, among other materials, "an assemblage of microfossils." The fossils were so unusual that their limestone source rock outcropped only in two highly confined areas. One of the outcrops was in Appalachian Pennsylvania and intersected a country road. (Information on the second outcrop is unavailable.) Rawalt provided this information to local police who found the officer's body the following day at the location where the outcrop intersects the road (8). It could not be confirmed that the microfossils in question were foraminifera, but it is likely that foraminifera were present in the assemblage due to their ubiquity in marine limestone.

**Burglary Case in Alabama**

A truck depot in a rural area south of Montgomery, AL, was robbed in the late 1970s. Several young men matching a description provided to the police were apprehended shortly after the robbery took place. Shoes from the suspects were submitted to the laboratory along with known soil samples from the truck depot lot and additional known soil samples from the surrounding area. The truck depot was built in a low lying swampy area, and the local soil could not support the weight of the trucks. Soil had been brought in from a location approximately 10 miles away to support the trucks. Microscopical examination of the imported soil from the truck depot lot revealed that it was composed primarily of foraminifera. Soil from the surrounding area was a fine clay soil and did not contain foraminifera. The soil recovered from the shoes of the suspects was a foraminifera-rich soil that was consistent with the soil from the truck depot but inconsistent with soil from the surrounding areas. The suspects were confronted with this information and pleaded guilty, according to Thomas J. Hopen, the analyst involved in the investigation. Hopen supplied the

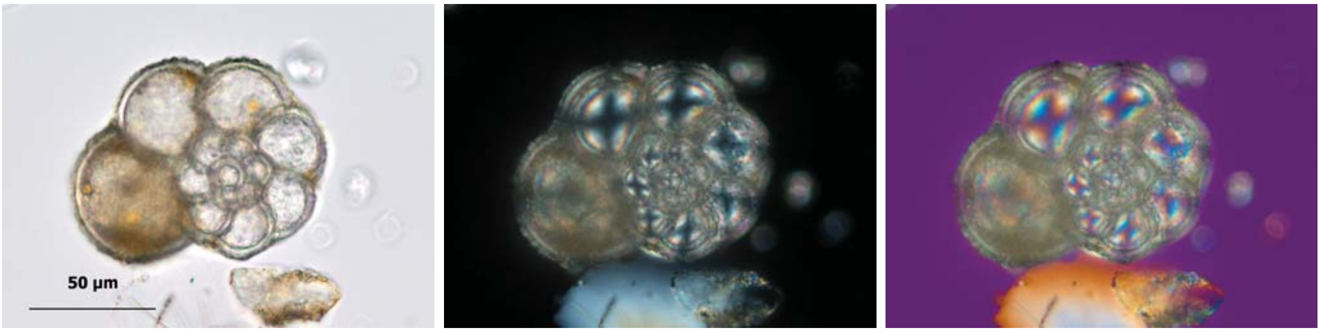



Figure 13. A foraminifer from an Alabama robbery case shown in plane-polarized light (left), in crossed polars (middle) and in crossed polars with a 530 nm compensator (right). The refractive index of the mounting medium is 1.540.

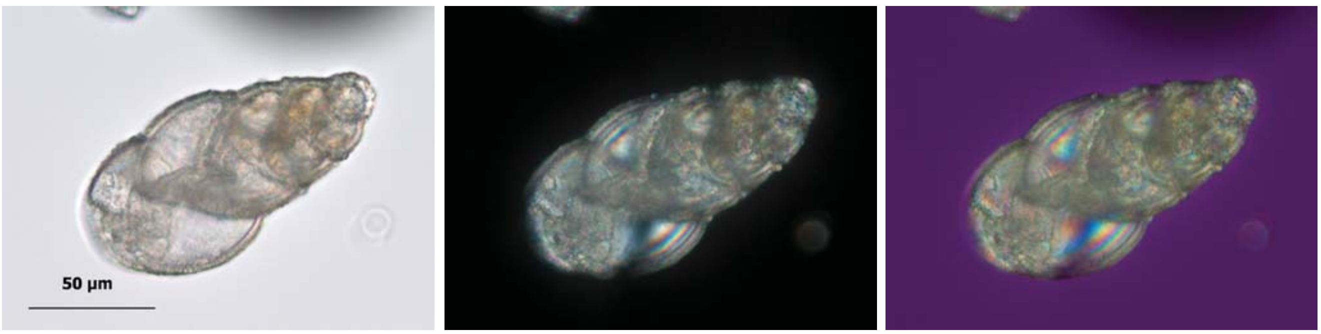



Figure 14. A foraminifer from an Alabama robbery case shown in plane-polarized light (left), in crossed polars (middle) and in crossed polars with a 530 nm compensator (right). The refractive index of the mounting medium is 1.540.

author with some of the foraminifera-rich soil from this case. Two specimens from the soil are shown in **Figures 13** and **14**.

## Stoney Forensic, Inc. Samples

Stoney Forensic, Inc. has observed foraminifera in 10 different samples submitted to the laboratory for analysis over the course of the past several years. They have been used for both investigative and comparative purposes. One recent problem included both a provenance determination and comparative analysis involving two foraminifera-containing samples.

### *Sample 1*

The item designated Sample 1 was submitted to the laboratory for a provenance determination. It was observed to contain a low minor amount of foraminifera (comprising just over 1% of the particles observed in the fine sand-sized fraction during point counting). A total of 98 foraminifera specimens were documented by both polarized light microscopy and scanning electron microscopy. Twenty-nine of these were identified to the species level, representing 11 different species; an additional 21 were identified to the genus level, representing 11 different genera; and 48 were too poorly preserved to be identified. Despite being unidentified, most of the latter could be characterized to some degree (i.e., unidentified biserial planktonic foraminifer). The foraminifera identified were all determined to be consistent with a late Campanian-Maastrichtian age (72-65 Ma) with one exception: *Favusella washitensis*, a late Albian-early Cenomanian species (102-98 Ma). Geologic maps of the target region were consulted to locate occurrences of Late Campanian-Maastrichtian marine sediments with outcrops of late Albian-early Cenomanian sediments nearby. This helped to significantly constrain the likely geographic source of Sample 1. A list of the taxa identified in Sample 1 is provided in **Table 1**.

Several of the identified specimens illustrating the variety of foraminifera present in the sample are shown in **Figures 15-19**.

### *Sample 2*

The item designated Sample 2 was submitted to the laboratory for comparison with Sample 1, to determine whether or not the two samples originated from the same location. Sample 2 was observed to con-

**Table 1. Foraminifera Taxa Identified in Sample 1**

| Genus | Species | Number of Specimens | Percent of Foraminifera |
|---|---|---|---|
| *Bolivina* | *sp.* | 2 | 2.0% |
| *Coryphostoma* | *incrassate* | 1 | 1.0% |
| *Favusella* | *washitensis* | 1 | 1.0% |
| *Globigerinelloides* | *sp.* | 5 | 5.1% |
| *Globigerinelloides* | *asperus* | 8 | 8.2% |
| *Guembelitria* | *cretacea* | 2 | 2.0% |
| *Hedbergella* | *sp.* | 1 | 1.0% |
| *Hedbergella* | *monmouthensis* | 1 | 1.0% |
| *Heterohelix* | *sp.* | 11 | 11.2% |
| *Heterohelix* | *navarroensis* | 1 | 1.0% |
| *Heterohelix* | *striata* | 10 | 10.2% |
| *Laeviheterohelix* | *dentata* | 2 | 2.0% |
| *Laeviheterohelix* | *glabrans* | 1 | 1.0% |
| *Pseudoguembelina* | *excolata* | 1 | 1.0% |
| *Rugoglobigerina* | *sp.* | 1 | 1.0% |
| *Rugoglobigerina* | *rugosa* | 1 | 1.0% |
| *Zeauvigerina* | *sp.* | 1 | 1.0% |
| Unidentified | Unidentified | 48 | 49.0% |
| Total | | 98 | 100.0% |

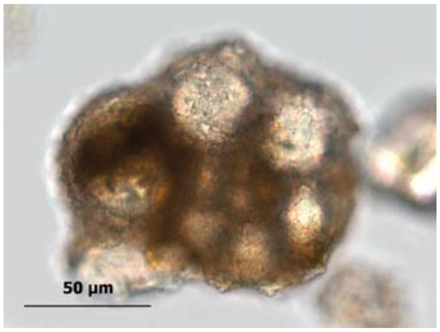
tain a trace amount of foraminifera (comprising just under 1% of the particles observed in the fine sand-sized fraction during point counting), consistent with their abundance in Sample 1. A total of 103 foraminifera specimens were documented by both polarized light microscopy and scanning electron microscopy. Forty-four of these were identified to the species level, representing 13 different species; an additional 35 were identified to the genus level, representing 13 different genera; and 24 were too poorly preserved to be identified. The foraminifera identified were determined to be consistent with a late Campanian-Maastrichtian age (72-65 Ma), and in fact, one species present (*Pseudoguembelina hariaensis*) indicated that the age of the source sediment was more precisely late Maastrichtian (66.8-65.5 Ma). All of the specimens identified were consistent with this age with the exception of four specimens of *Subbotina cancellata*, an early-late Paleocene species (61-57 Ma). A list of the identified taxa from Sample 2 is provided in **Table 2**.

Several of the identified specimens illustrating the variety of foraminifera present in the sample are shown in **Figures 20-25**.

***Comparison of Sample No. 1 and Sample No. 2***

The comparison between the two samples was based on several different properties, including the relative abundances of minerals in the various size fractions of the soil, the pollen assemblages present, the anthropogenic material observed and the botanical macerals that could be identified in the two samples. The foraminifera in the two samples provided an additional criterion for comparison, which was used together with all of the other data to reach a conclusion. **Table 3** compares the relative abundances of different foraminifera taxa in the two samples. There were a few similarities with respect to the foraminifera identified in the two samples. Both sample sets were dominated by species from the late Campanian-Maastrichtian (although there were small amounts of forams of different ages in each sample). In addition, there were significant amounts of *Heterohelix sp*. in both samples.

Despite these similarities, the differences between the two samples were much more significant. There were a greater percentage of unidentified specimens in Sample 1, reflecting the generally poor preservation of most of the specimens in this sample. Sample 2, on the



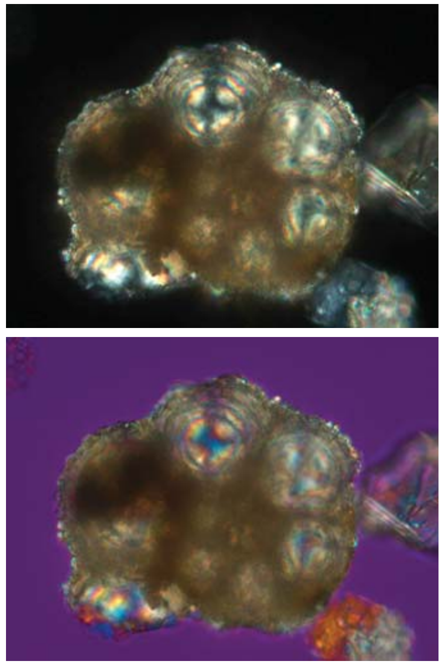
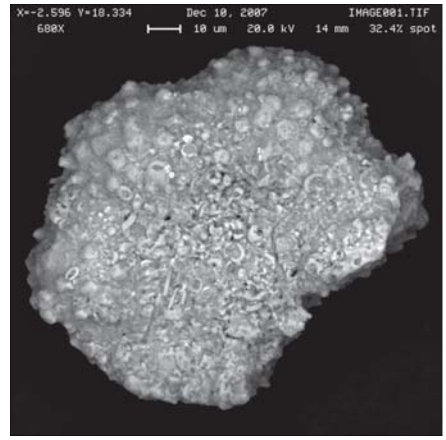
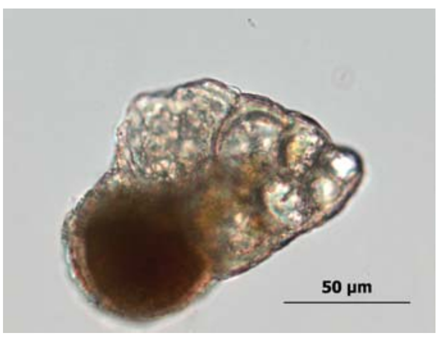




Figure 15. A *Rugoglobigerina rugosa* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).



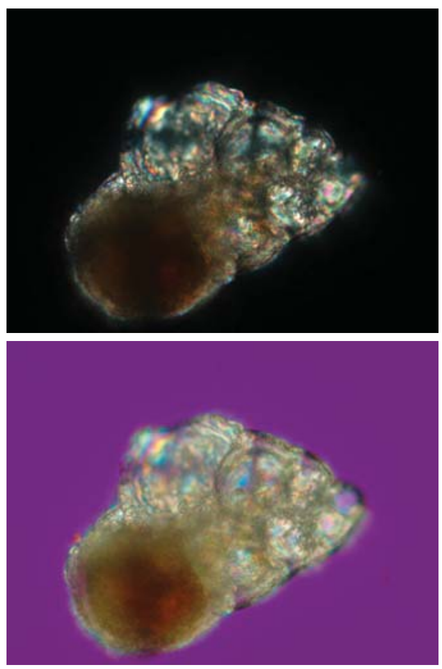
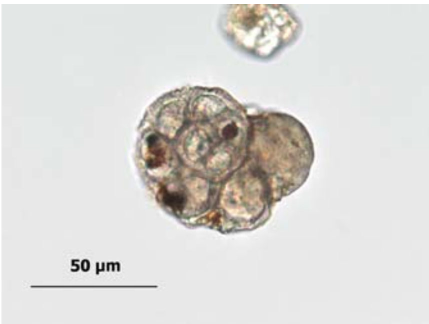




Figure 16. A *Heterohelix striata* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

other hand, contained primarily well-preserved specimens and the majority of these could be identified to at least the genus level. Of 32 taxa that were identified, only nine taxa were common to both samples. Three of the taxa that were present in one sample but absent in the other were major components of their respective samples (*Globigerinelloides sp.*, *Globigerinelloides asperus* and *Heterohelix globulosa*). Differences in the relative abundance of several taxa also stood out. Specimens assigned to the genus *Globigerinelloides* were a major component of Sample 1 (13%), but only a low minor component of the specimens from Sample 2 (3%). Specimens assigned to the genus *Hedbergella* were a low minor component of the specimens from Sample 1 (2%), but a major component of the specimens from Sample 2 (16%). This data was used along with differences in the mineralogy, pol-



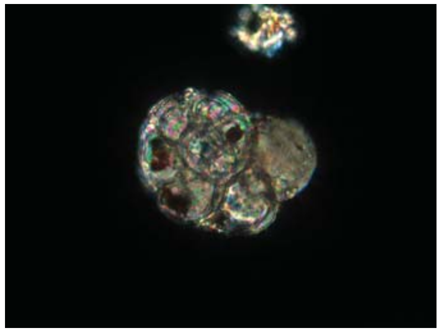
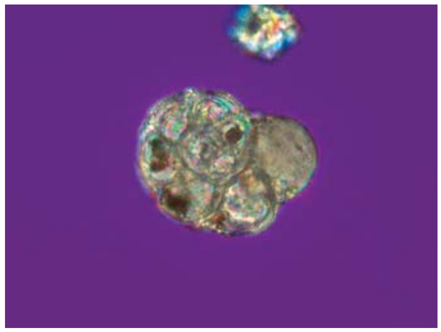





Figure 17. A *Hedbergella sp.* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

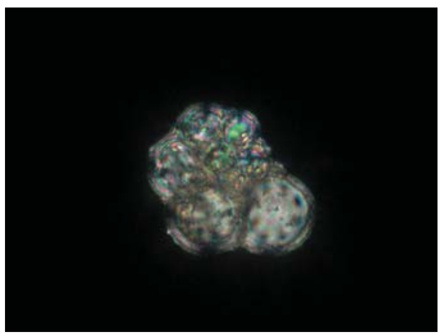
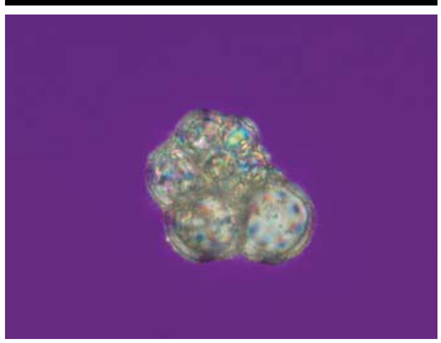



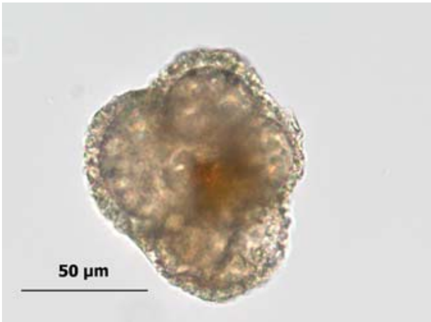


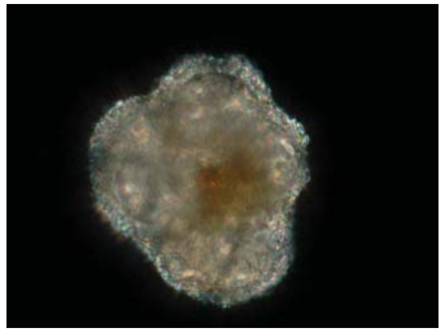
Figure 18. A *Globigerinelloides asperus* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

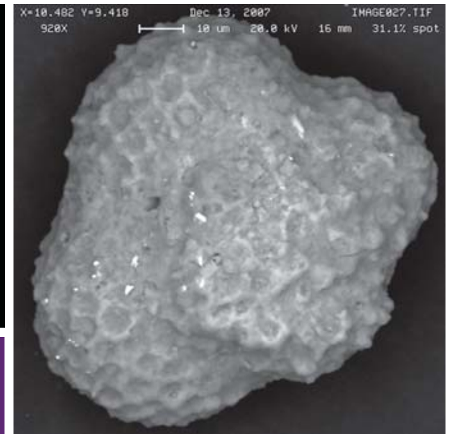
len assemblages, botanical macerals and anthropogenic material in the two samples to conclude that the two samples submitted did not share a common source.

## CONCLUSIONS

Foraminifera are used extensively by sedimentary geologists to determine the age of sedimentary rocks. They are extremely useful for this application because of their widespread occurrence, great variability and generally good preservation (due to their small size). They are well described in literature, and there are many practicing experts who are able to identify them. Many of the properties that make foraminifera useful to geologists are equally likely to make them useful for forensic scientists performing soil comparisons and





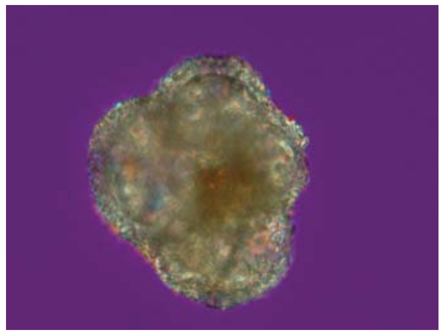



Figure 19. A *Favusella washitensis* specimen shown in plane-polarized light (left), in crossed polars (middle top) and again in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

provenance determinations. Despite their potential, only three published cases and one additional unpublished case that utilized foraminifera to solve forensic problems were discovered. While there are likely additional unreported cases, this still seems to be a very small number considering their potential.

One possible explanation for the paucity of case examples is that untrained analysts may fail to recognize foraminifera when they occur in samples. They would then be overlooked when present in forensic soil samples (indeed, the author has failed to recognize foraminifera in a sample on at least one occasion). Large, well-preserved foraminifera are hard to miss when examining a sample by polarized light microscopy. However, smaller specimens or fragments in poor condition are easily overlooked. **Figures 26** and **27** illustrate two specimens that were somewhat poorly preserved. Despite their fairly poor preservation, they were both successfully identified at least to the genus level and proved extremely useful for comparative purposes in a sample that contained only a very small number of microfossil specimens.

A second possibility is that foraminifera are observed and noted by forensic scientists in soil samples, but that their potential utility is not recognized by the analyst and their identification is, therefore, not pursued. Finally, it is conceivable that foraminifera are not encountered in forensic samples nearly as frequently as the author suspects.

Regardless of their precise frequency of occurrence in forensic samples, the author's personal experience confirms that they can in fact be found in a variety of unrelated samples. It is the author's hope that they will gain more attention from the forensic community and be utilized more frequently to help solve forensic cases in the future. If the reader is a practicing forensic scientist, and there are fossiliferous marine sediments in the reader's jurisdiction, it is worth the effort to determine which taxa occur in these sediments so that one will be able to recognize them if encountered during casework. It would also be advisable to make the acquaintance of experts at local universities or state geological surveys who would be able to assist with identifications of foraminifera and interpretation of their significance in the event that they are encountered during casework.

## ACKNOWLEDGMENTS

The author would like to acknowledge David Exline for taking the SEM images used in this paper, and for all of his help with these and many other cases. The author would like to thank Dr. Raymond Murray and Dr. David Rogers for their assistance in tracking down information regarding historical case examples. Finally, the author would like to thank Thom Hopen for sharing details of the Alabama burglary case that he worked on and for providing some soil from the case for the author's examination and enjoyment.

**Table 2. Foraminifera Taxa Identified in Sample 2**

| Genus | Species | Number of Specimens | Percent of Foraminifera |
|---|---|---|---|
| *Aragonia* | *sp.* | 1 | 1.0% |
| *Chiloguembelina* | *sp.* | 2 | 1.9% |
| *Globigerinelloides* | *subcarinatus* | 2 | 1.9% |
| *Globigerinelloides* | *ultramicrus* | 1 | 1.0% |
| *Globotruncana* | *sp.* | 2 | 1.9% |
| *Gublerina* | *sp.* | 2 | 1.9% |
| *Gyroidinoides* | *globosus* | 1 | 1.0% |
| *Hedbergella* | *sp.* | 13 | 12.6% |
| *Hedbergella* | *monmouthensis* | 3 | 2.9% |
| *Heterohelix* | *sp.* | 10 | 9.7% |
| *Heterohelix* | *globulosa* | 13 | 12.6% |
| *Heterohelix* | *navarroensis* | 2 | 1.9% |
| *Heterohelix* | *planata* | 6 | 5.8% |
| *Heterohelix* | *striata* | 5 | 4.9% |
| *Laeviheterohelix* | *dentata* | 2 | 1.9% |
| *Pseudoguembelina* | *sp.* | 4 | 3.9% |
| *Pseudoguembelina* | *excolata* | 1 | 1.0% |
| *Pseudoguembelina* | *hariaensis* | 3 | 2.9% |
| *Quinqueloculina* | *sp.* | 1 | 1.0% |
| *Rugoglobigerina* | *hexacamerata* | 1 | 1.0% |
| *Subbotina* | *cancellata* | 4 | 3.9% |
| Unidentified | Unidentified | 24 | 23.3% |
| Total | | 103 | 100.0% |

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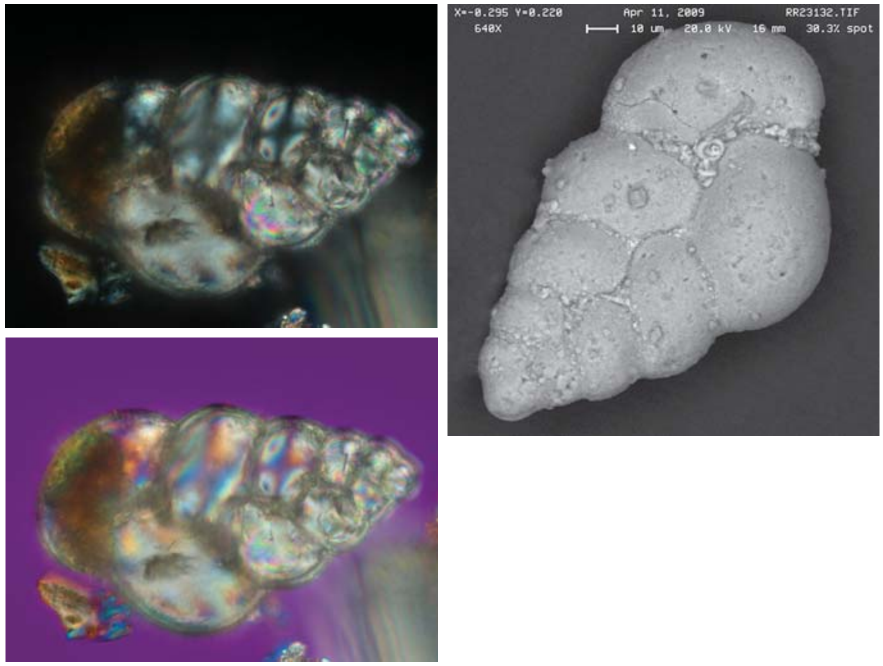
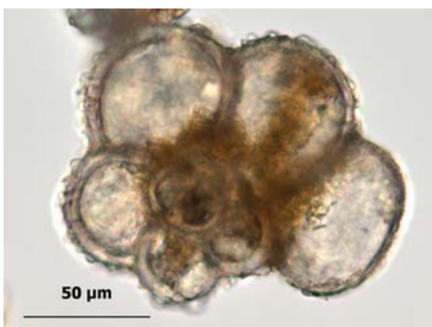



Figure 20. A *Laeviheterohelix dentata* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).



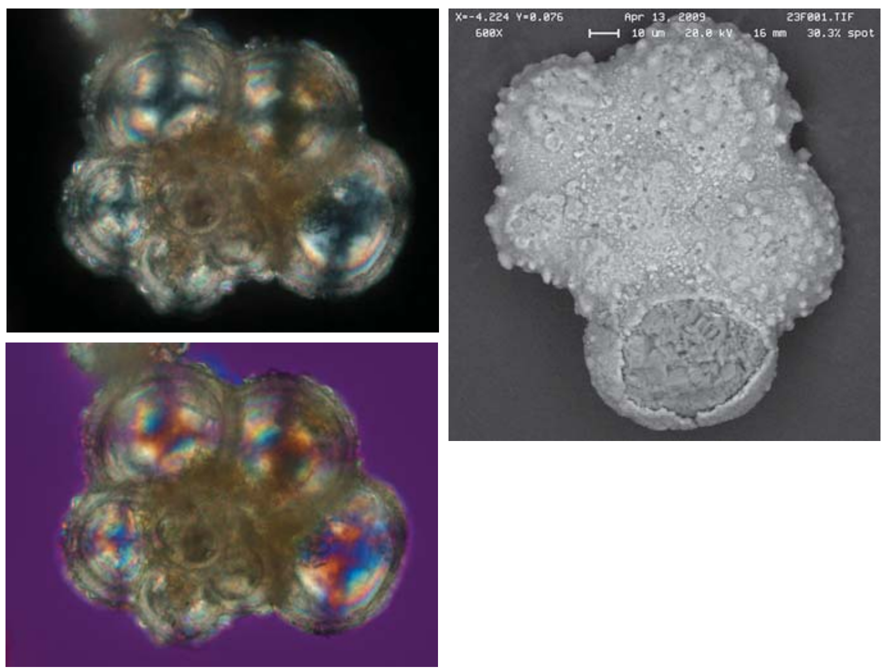
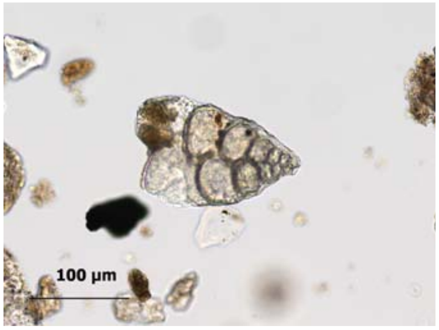
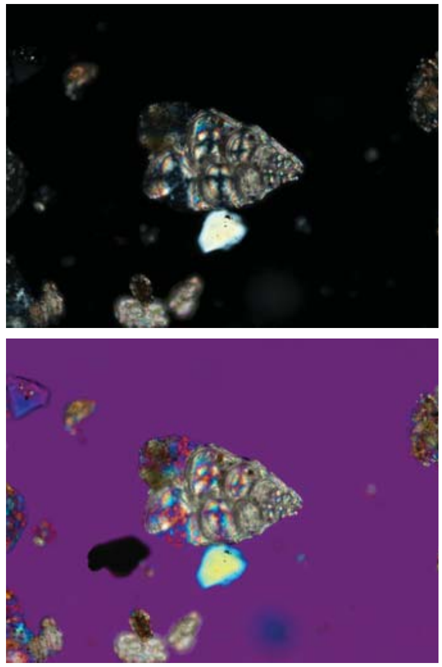




Figure 21. A juvenile *Rugoglobigerina hexacamerata* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).



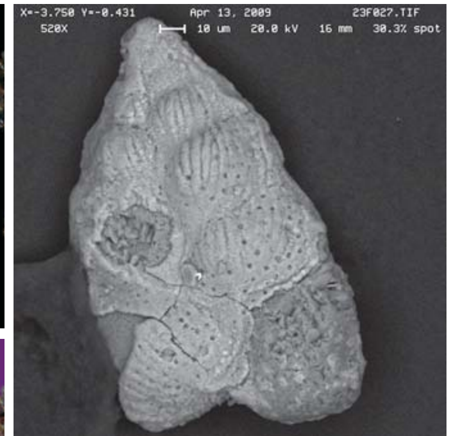



Figure 22. A *Pseudoguembelina hariaensis* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

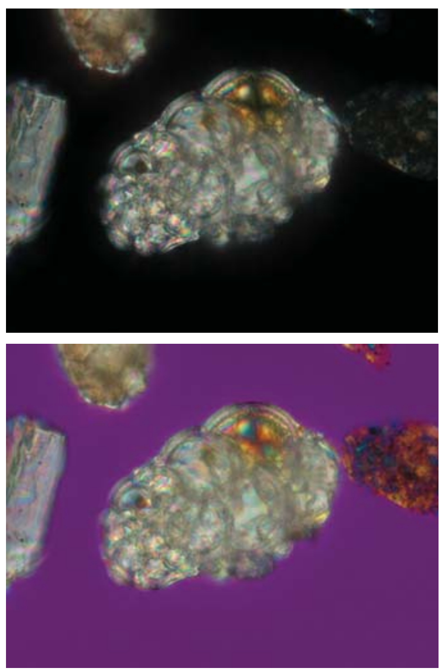
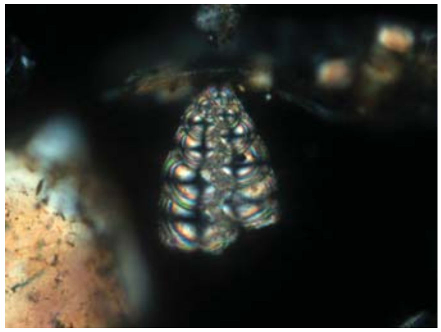




Figure 23. A *Heterohelix navarroensis* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

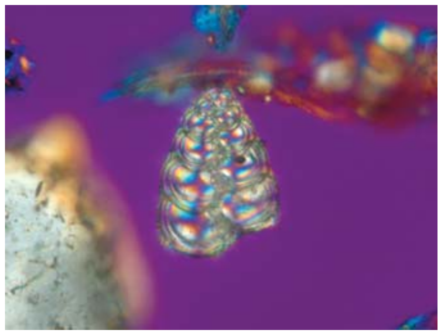
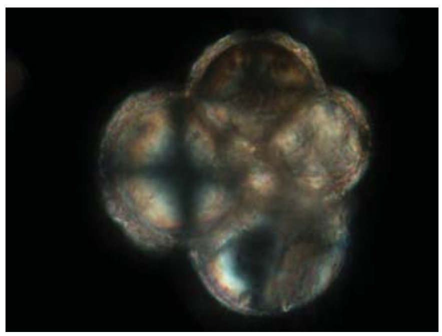
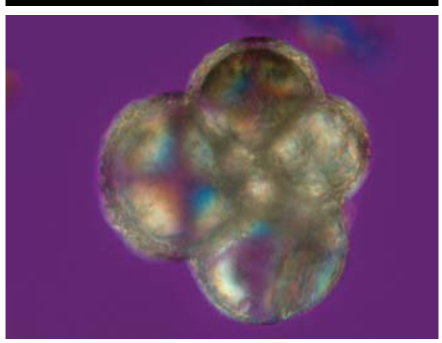



Figure 24. A *Heterohelix planata* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).



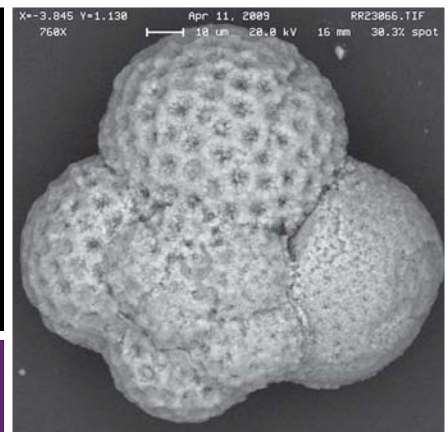
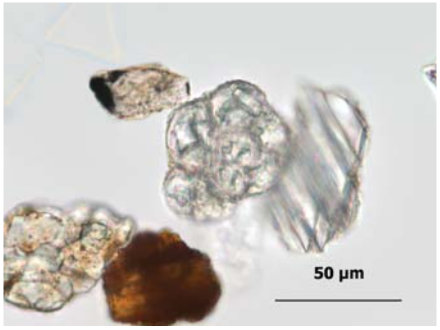



Figure 25. A *Subbotina cancellata* specimen shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle botttom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).

**Table 3. Foraminifera Taxa and Their Relative Abundances in the Two Samples**

| Genus | Species | Percentage in Sample 1 | Percentage in Sample 2 |
|---|---|---|---|
| *Aragonia* | *sp.* | – | 1.0% |
| *Bolivina* | *sp.* | 2.0% | – |
| *Chiloguembelina* | *sp.* | – | 1.9% |
| *Coryphostoma* | *incrassata* | 1.0% | – |
| *Favusella* | *washitensis* | 1.0% | – |
| *Globigerinelloides* | *sp.* | 5.1% | – |
| *Globigerinelloides* | *asperus* | 8.2% | – |
| *Globigerinelloides* | *subcarinatus* | – | 1.9% |
| *Globigerinelloides* | *ultramicrus* | – | 1.0% |
| *Globotruncana* | *sp.* | – | 1.9% |
| *Gublerina* | *sp.* | – | 1.9% |
| *Guembelitria* | *cretacea* | 2.0% | – |
| *Gyroidinoides* | *globosus* | – | 1.0% |
| *Hedbergella* | *sp.* | 1.0% | 12.6% |
| *Hedbergella* | *monmouthensis* | 1.0% | 2.9% |
| *Heterohelix* | *sp.* | 11.2% | 9.7% |
| *Heterohelix* | *globulosa* | – | 12.6% |
| *Heterohelix* | *navarroensis* | 1.0% | 1.9% |
| *Heterohelix* | *planata* | – | 5.8% |
| *Heterohelix* | *striata* | 10.2% | 4.9% |
| *Laeviheterohelix* | *dentata* | 2.0% | 1.9% |
| *Laeviheterohelix* | *glabrans* | 1.0% | – |
| *Pseudoguembelina* | *sp.* | – | 3.9% |
| *Pseudoguembelina* | *excolata* | 1.0% | 1.0% |
| *Pseudoguembelina* | *hariaensis* | – | 2.9% |
| *Quinqueloculina* | *sp.* | – | 1.0% |
| *Rugoglobigerina* | *sp.* | 1.0% | – |
| *Rugoglobigerina* | *hexacamerata* | – | 1.0% |
| *Rugoglobigerina* | *rugosa* | 1.0% | – |
| *Subbotina* | *cancellata* | – | 3.9% |
| *Zeauvigerina* | *sp.* | 1.0% | – |
| Unidentified | Unidentified | 49.0% | 23.3% |



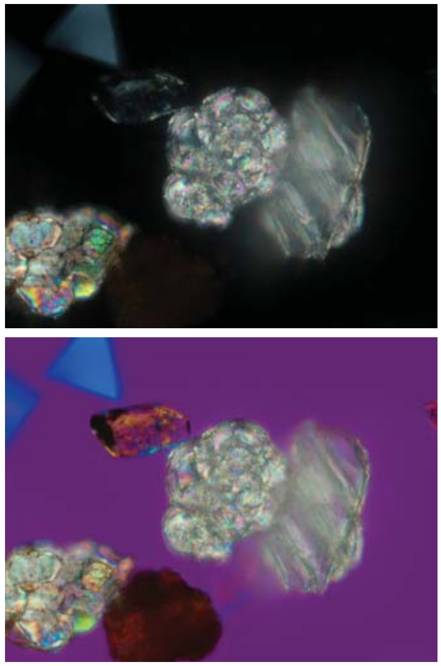
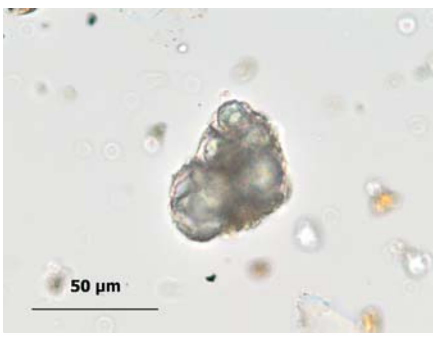




Figure 26. A small, poorly preserved foraminifer shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).



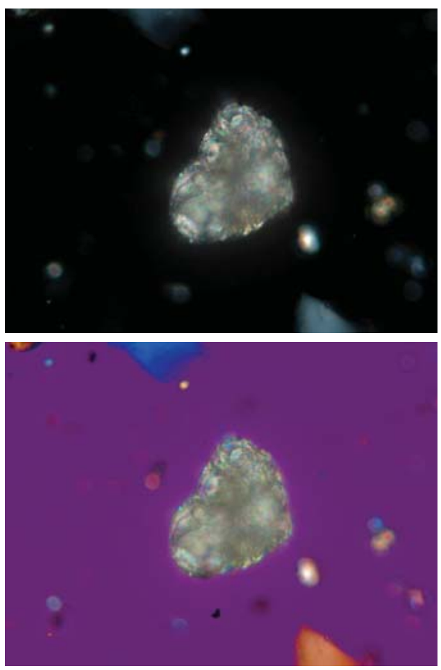
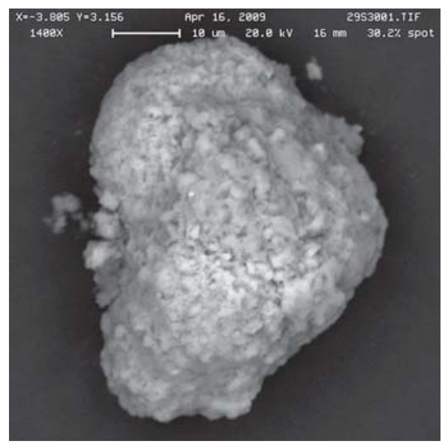




Figure 27. A small, poorly preserved foraminifer shown in plane-polarized light (left), in crossed polars (middle top) and in crossed polars with a 530 nm compensator (middle bottom). The refractive index of the mounting medium is 1.540. An SEM image shows the same specimen (right).