# Great Moments in Microbial Evolution

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## Abstract

The vast expanse of Earth's history, featuring the predominance of microorganisms, is explored in four activities with increasing levels of student control. The chronology of evolution is converted proportionally to either distance (500 m and 5 m) or familiar time scales (year, month, and day). (i) Students travel a 500 m course across campus. (ii) Students stand at points along a 5 m line. (iii) Students work in small groups to identify the relative positions on a more familiar time scale. (iv) Students are given the approximate dates of key events and then must calculate and plot events on a calendar.

## Activity

**Invitation for User Feedback.** If you have used the activity and would like to provide feedback, please send an e-mail to MicrobeLibrary@asmusa.org. Feedback can include ideas which complement the activity and new approaches for implementing the activity. Your comments will be added to the activity under a separate section labeled "Feedback." Comments may be edited.

**Editor's Note (2008):** This Curriculum Resource was published prior to establishment of current criteria of submission, and as such, does not contain all criteria required of current publications. However, the Editorial Committee felt that the activity itself remained worthwhile and relevant, and encourages potential users to contact the authors for clarification as needed. If you do update this activity for use with your students, and are interested in updating the resource for distribution in the library, please contact ASM at MicrobeLibrary@asmusa.org.

### INTRODUCTION

**Time Required.**
Activity 1: 30 to 45 minutes
Activity 2: 10 to 20 minutes without follow-up; additional 10-15 minutes for discussion.
Activity 3: 10 to 20 minutes without follow-up; additional 10-15 minutes for discussion.
Activity 4: 10 to 20 minutes without follow-up; additional 10-15 minutes for discussion.

**Pedagogical Function.**
These activities were designed to aid students in comprehending the scale of evolutionary history and the predominance of microbes throughout time. The activities provide an opportunity to describe empirical and speculative information on the sequence of development of key metabolic events. The interactions (positive, negative, or neutral) between microbes and other organisms, as the latter evolve, provides previews of and insight into the niches of modern day ecological (and medical) relationships. The activities can be used to introduce information that subsequently can be used to distinguish differences between phylogenetic and metabolic or functional classification systems, as well as the unique values of both. Finally, the activities emphasize the constant refining of knowledge intrinsic to scientific inquiry.

**Learning Objectives.**
At the completion of these activities students should be able to:

- Identify significant events in microbial evolution;
- Translate information from one mathematical scale to another;
- Understand the perennial dominance of microbes, past and present; and
- Understand the order of key events in evolution relating to microbes.

**Background.**
Students need not have any special training prior to participation in any of the four activities. However, students should be familiar with basic terms typically introduced in the first weeks of a microbiology course (autotroph, heterotroph, etc.).

### PROCEDURE

**Materials.**
Activity 1. None.
Activity 2. None (calculator optional).
Activity 3. None.
Activity 4. Calculator.

**Instructor Version.**
*Activity 1.* "Walk (Run and Tumble) Through Time" (500 m). The instructor leads students along a 500 m path representing the evolutionary history of the planet. Students receive a handout listing evolutionary eras and epochs, with space to record notes. The instructor presents a brief summary of key events at premeasured distances proportional to the time elapsed since the formation of earth.

Appendix 1. Topics for Walk (Run and Tumble)
Figure 1. Walk (Run and Tumble) Through Time - Handout for Activity 1

*Activity 2.* "A Line Across Time" (5 m or 5 cm). Students begin by working in small groups to identify the position of one or more events, with the total of selected events divided among all groups. After a short period for analysis, each group directs the positioning of their representative along a 5 m line in front of the room. Their positions are proportional to time elapsed, where the left side represents the formation of the planet and the right side represents the present. Alternatively, students mark the positions of their assigned events on a 5 cm line on paper.

Appendix 1. Topics for Walk (Run and Tumble)
Figure 2A. A Line Across Time - Instructions (Scale = 5 m line in classroom)
Figure 2B. A Line Across Time - Worksheet (Scale = 5 m line in classroom)
Figure 2C. A Line Across Time - Instructions (Scale = 15 cm line on paper)
Figure 2D. A Line Across Time - Worksheet (Scale = 15 cm line on paper)

*Activity 3.* "Time Flies, No Matter What the Scale" (plotting only). Students, working in small groups, receive a list of evolutionary events correlated with modern calendars. They also receive a calendar template (year, month, or day). Each group then plots the evolutionary events on the template.

Figure 3. Time Flies, No Matter What the Scale - Instructions
Figure 4. Table of Useable Units
Figure 5. Calendar Template – One Year
Figure 6. Calendar Template – One Month
Figure 7. Calendar Template – One Day (military time format)
Figure 8. Calendar Template – One Year ("planner" time format)

*Activity 4.* "Time Flies, No Matter What the Scale" (calculation and plot). Students, working in small groups, receive a list of evolutionary events. They are directed to calculate the correlation of each event, on a proportional basis, with the time frame of a modern calendar. They also receive a calendar template (year, month, or day). Each group completes the calculation for one or more time points, then plots the evolutionary events on the template. Individual groups may be assigned one or more time points, with subsequent reports from each group being recorded on a common template (e.g., placed on an overhead projector).

Figure 9A. Time Flies, No Matter What the Scale - Instructions (Scale = Year)
Figure 9B. Time Flies, No Matter What the Scale - Worksheet (Scale = Year)
Figure 9C. Time Flies, No Matter What the Scale - Instructions (Scale = Month)
Figure 9D. Time Flies, No Matter What the Scale - Worksheet (Scale = Month)
Figure 9E. Time Flies, No Matter What the Scale - Instructions (Scale = Day)
Figure 9F. Time Flies, No Matter What the Scale - Worksheet (Scale = Day)
Figure 5. Calendar Template – One Year
Figure 6. Calendar Template – One Month
Figure 7. Calendar Template – One Day (military time format)
Figure 8. Calendar Template – One Year ("planner" time format)

**Safety Issues.** Not applicable.

**ASSESSMENT and OUTCOMES**

**Suggestions for Assessment.**

- Peer oral assessment is incorporated into the activities through group discussion and whole class discussion and feedback.
- Immediate instructor feedback is incorporated in Activities 2, 3, and 4 at the completion of each example.
- Concepts can be included on a subsequent quiz or exam using either a map (as in Activity 1) or a calendar (as in Activities 3 and 4).

**Problems and Caveats.**
Prior to performing activity 1, the instructor will need to measure out and identify stops to represent the evolutionary events. The 500 m distance is about the length of one long campus block. I end the "Walk" in the microbiology lab; that puts the Cambrian events at the front door of the building and all the subsequent events inside in the hallways or in the lab. I use visuals (some figures from books, etc.) to illustrate events along the way, for the ones inside the building, I hang them up on the walls.

**SUPPLEMENTARY MATERIALS**

**Possible Modifications.**
The amount of detail required can be varied based on time available and background of the students. Different distance or time scales can be used. Calculations can be assigned for completion outside of class.

**Appendices.**
Appendix 1. Topics for Walk (Run and Tumble) Through Time (all activities)

Appendix 2. Correlation of Events with Distances (Activities 1 & 2)
Appendix 3. Correlation of Events with Modern Calendars (Activities 3 & 4)

**References.**

*General microbiology textbooks*
a) Books with directly related features (figures, tables)

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* Part 5. Microbial evolution and diversity.
* A conversation with Carl Woese, p. 384-387.
* Ch. 17. Taxonomy of Eubacteria and Archaea, p. 388-413.
* Ch. 18. Evolution, p. 414-429.
* Table 18.1. Geological timetable of Earth, p. 415.
* Table 18.2. Precambrian geological timetable of Earth, p. 416.
* Figure 18.1. Fossil stromatolites, p. 417.
* Figure 18.2. Modern stromatolites, p. 417.
* Figure 18.4. Miller's apparatus, p. 419.
* Figure 18.5. Artist's rendition of pre-Cambrian Earth, p. 421.
* Figure 18.7. Possible pre-Cambrian nitrogen cycle, p. 424.
* Figure 18.8. Evolution of main lines of descent, p. 425.

** Many major microbial events included.

* Figure 18.11. Timetable of major geological events, p. 427.

** Also found inside front cover.

**Madigan, M. T., J. M. Martinko, and J. Parker.** 2000. Brock biology of microorganisms, 9th ed. Prentice Hall, Upper Saddle River, N. J.
* Ch. 12. Microbial evolution and systematics, p. 422-452.
* Figure 12.1. Ancient and modern stromatolites, p. 425.
* Figure 12.2. Fossil prokaryotes and eukaryotes, p. 426.
* Figure 12.3. Overview of major events leading to cellular life, p. 427.
* Figure 12.5. Major landmarks in biological evolution, p. 429.
* Figure 12.6. Endosymbiotic events, p. 431.

**Atlas, R. M.** 1997. Principles of microbiology, 2nd ed. Wm. C. Brown, Dubuque, Iowa.
* Ch. 16. Microbial systematics: evolution, phylogeny, and classification, p. 888-957.
* Figure 16-1. Precambrian fossilized photosynthetic bacteria, p. 888.
* Figure 16-2. Geological and evolutionary time scale, p. 889.

b) Other general microbiology texts

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* Ch. 16. Prokaryotes, p. 650-692.
* Box 16-1. Ribosomal RNA (rRNA) and phylogeny, p. 656-658.

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* Ch. 2. Diversity of the microbial world, p. 24-57.
* Figure 2-4. Endosymbiotic theory, p. 29.

**Black, J. G.** 1999. Microbiology: principles and explorations, 4th ed. Prentice-Hall, Englewood Cliffs (Upper Saddle River), N.J.
* Ch. 9. Microbes in the scheme of life: an introduction to taxonomy, p. 226-245.
* Essay: evolution from a universal common ancestor, p. 241-242.

**Ingraham, J. L. and C. A. Ingraham.** 1995. Introduction to microbiology. Wadsworth, Belmont, Calif.
* Ch. 10. Classification, p. 230-247.

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**Pelczar, M. J., Jr., E. C. S. Chan, and N. R. Krieg.** 1993. Microbiology: concepts and applications. McGraw-Hill, New York, N.Y.
* Ch. 2. The Scope of Microbiology, p. 56-79.
* Figure 2.6. Endosymbiotic theory, p. 65.

**Prescott, L. M., J. P. Harley, and D. A. Klein.** 1999. Microbiology, 4th ed. Wm. C. Brown Publishers, Dubuque, Iowa.
* Ch. 19. Microbial taxonomy, p. 394-420.
* Figure 19.1. Fossilized bacteria.
* Figure 19.2. Stromatolites.

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* Ch. 10. Classification of microorganisms, p. 250-272.
* Figure 10.4. Fossilized procaryotes, p. 256.

**Volk, W. A. and J. C. Brown.** 1997. Basic microbiology, 8th ed. Benjamin/Cummings, Menlo Park, Calif.
* Ch. 13. Classification schemes for common procaryotes, p. 266-278.

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a) Introductory texts

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* Ch. 17. The history of life on Earth, p. 311-335.
* Figure 17-2. The experimental apparatus of Miller and Urey, p. 313.
* Table 17-1. The history of life on Earth, p. 316.

**This has selected events plotted on a stopwatch representing one 24-hour day.

* Figure 17-4. Endosymbiotic theory diagram, p. 318.
* Figure 17-5. Modern symbiosis photo, p. 319.
* Figure 17-8. Artist's rendition of Carboniferous swamp forest, p. 322.
* Figure 17-11. Artist's rendition of Cretaceous forest, p. 324.

**Starr, C. and R. Taggart.** 1998. Biology: the unity and diversity of life, 8th ed. Wadsworth Publishing Company, Belmont, Calif.
* Ch. 21. The origin and evolution of life, p. 332-351.
* Figure 21.2. Artist's rendition of disperse material orbiting sun prior to planet formation, p. 334.
* Figure 21.3a. Artist's rendition of Hadean Earth surface, p. 335.
* Figure 21.3b. The experimental apparatus of Miller, p. 335.
* Figure 21.6. Possible sequence from prebiotic molecules to cells, p. 337.
* Figure 21.7. Timeline of major events and divergence of major lineages in evolution, p. 338-339.
* Figure 21.8. Modern stromatolites, p. 338.
* Figure 21.9. Fossil cells (prokaryote and eukaryote), p. 340.
* Figure 21.11. Details of membranes in endosymbiotic organelle formation, p. 341.
* Figure 21.12. EM of extant cell and similarity to Fig. 21.11, p. 341.
* Figure 21.20. Summary of major events in evolution, p. 348-349.

b) Advanced texts

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* Figure 28-1. Fossil cells, p. 1099.
* Figure 28-2. Apparatus for prebiotic synthesis of organic molecules, p. 1011.
* Figure 28-25. Possible scheme for early evolution, p. 1155.

** Excellent source for those molecular and biochemical steps.

*Other resources*

a) Primary, secondary, and tertiary (general audience) articles

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6. **Margulis, L. and K. V. Schwartz.** 1988. Five kingdoms: an illustrated guide to the phyla of life on earth, 2nd ed. W. H. Freeman and Company, San Francisco, Calif.
* Introduction, p. 1-21.
* Figure I-4. A geologic chronology of Earth history, p. 16-17.
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13. **Vidal, G.** 1984. The oldest eukaryotic cells. Sci. Am. **250**:48-57.
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*Other resources*

**Folsome, C. E.** 1979. Life: origin and evolution – readings from Scientific American. W. H. Freeman, San Francisco, Calif. **The Museum of Paleontology, University of California, Berkeley.** 2000, copyright date. The phylogeny of life. [Online.] http://www.ucmp.berkeley.edu/alllife/threedomains.html. [13 March 2000, last date accessed.] **Woese, C. R.** 1984. The origin of life. Carolina Biological Supply Company, Burlington, N.C.
* Printed guide to accompany slide set of 20 or 79 frames.

Curriculum Resources

# Figure 1. Great Moments in Microbial Evolution - Handout for Activity 1

| Era | Period | Epoch | Stop | Events and Topics |
|---|---|---|---|---|
| - | | | | |
| Archean | | | 1 | . |
| - | | | | |
| Proterozoic | | | 2 | . |
| | | | 3 | . |
| | | | 4 | . |
| | | | 5 | . |
| | | | 6 | . |
| - | | | | |
| Paleozoic | | | | |
| | Cambrian | | 7 | . |
| | Ordovician | | 8 | . |
| | Silurian | | 9 | . |
| | Devonian | | 10 | . |
| | Carboniferous | | 11 | . |
| | Permian | | 12 | . |
| - | | | | |

| | | | | |
|---|---|---|---|---|
| **Mesozoic** | | | | |
| | **Triassic** | | 13 | . |
| | **Jurassic** | | 14 | . |
| | **Cretaceous** | | 15 | . |
| - | | | | |
| **Cenozoic** | | | | |
| | **Tertiary** | | 16 | . |
| | **Quaternary** | | | . |
| | | **Pleistocene** | 17 | . |
| | | **Recent** | 18 | . |
| | | | 19 | . |
| | | | 20 | . |

Curriculum Resources

## Figure 2A. A Line Across Time - Instructions
**(Scale = 5 m line in classroom)**

Many sources on the evolution of organisms on Earth are sadly lacking in topics related to microbes. Further, within microbiology, we often fail to integrate our organisms with the others, as well as with specific physiological changes that had dramatic effects on the course of evolution. In this activity, you and the members of your team will examine selected events from the history of this planet. You will convert the historical date assigned to these events into a position within a more familiar distance scale to aid you in viewing evolution in its proper scale.

Your team should receive these instructions, a worksheet for recording your calculations, and a list of events in evolution. Please begin by recording the names of your team members on the worksheet. Your team will be assigned events from evolutionary (and geological) history. Perform the calculations and record the results on the worksheet. Once your complete each conversion from historical time to the appropriate length, you will be asked to help position classmates along a 5 m line drawn in the classroom.

1. First, identify this "Event" on the worksheet.
2. Enter the "Historical date" currently assigned to this event
3. Subtract the historical date from the age of the Earth (4.5 billion years = 4,500 million years). {This "Time elapsed" value represents the length of time that passed between the formation of Earth and the occurrence of this event.}
4. Divide the time elapsed value by the total age of the Earth, and multiply by 100%. {This "Percent elapsed" value is the proportion of Earth's history that passed before this event.}
5. Identify the total distance on the scale (5 meters).
6. Multiply the percent time elapsed by the total distance on the scale.
7. Find and mark this point on the scale.
8. Repeat these steps for each of the events assigned to your team.
9. When completed, review your results.
10. Your instructor will ask one member of the team to come to the front of the room at a position representing this event.

An example: Event--first cell.

Historical Date: 3.5 BYA
Time Elapsed: 4.5 BY – 3.5 BY = 1.0 BY
Percent Elapsed: (1.0 / 4.5 ) x 100% = 22%
Length of Current Scale: 5 m
Location on Current Scale: 5 x .22 = 1.1
*1.1 meter from left end (point of origin).*

Curriculum Resources

## Figure 2B. A Line Across Time - Worksheet
**(Scale = 5 m line in classroom)**

**Names of Team Members:**

**Calculations:**

| Event | Time frame (years ago) | Time elapsed | Units (%) | Line (5 m) |
|---|---|---|---|---|
| 1 | - | - | - | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8 | - | - | - | - |
| 9 | - | - | - | - |
| 10 | - | - | - | - |
| 11 | - | - | - | - |
| 12 | - | - | - | - |
| 13 | - | - | - | - |
| 14 | - | - | - | - |
| 15 | - | - | - | - |
| 16 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **17** | - | - | - | - |
| **18** | - | -- | - | - |
| **19** | - | - | - | - |
| **20** | - | - | - | - |

Curriculum Resources

## Figure 2C. A Line Across Time - Instructions
**(Scale = 15 cm line on paper)**

Many sources on the evolution of organisms on Earth are sadly lacking in topics related to microbes. Further, within microbiology, we often fail to integrate our organisms with the others, as well as with specific physiological changes that had dramatic effects on the course of evolution. In this activity, you and the members of your team will examine selected events from the history of this planet. You will convert the historical date assigned to these events into a position within a more familiar distance scale to aid you in viewing evolution in its proper scale.

Your team should receive these instructions, a worksheet for recording your calculations, and a list of events in evolution. Please begin by recording the names of your team members on the worksheet. You will also receive a page with a 15 cm line on it. Your team will be assigned events from evolutionary (and geological) history. Perform the calculations and record the results on the worksheet. Once your complete each conversion from historical time to the appropriate length, mark the position of that event on the line.

1. First, identify this "Event" on the worksheet.
2. Enter the "Historical date" currently assigned to this event
3. Subtract the historical date from the age of the Earth (4.5 billion years = 4,500 million years). This "Time elapsed" value represents the length of time that passed between the formation of Earth and the occurrence of this event.
4. Divide the time elapsed value by the total age of the Earth, and multiply by 100%. This "Percent elapsed" value is the proportion of Earth's history that passed before this event.
5. Identify the total distance on the line (15 cm).
6. Multiply the percent time elapsed by the total distance on the scale.
7. Find and mark this point on the scale.
8. Repeat these steps for each of the events assigned to your team.
9. When completed, review your results.
10. Submit this assignment as directed by your instructor.

An example: Event--first cell.

Historical date: 3.5 BYA
Time elapsed: 4.5 BY – 3.5 BY = 1.0 BY
Percent elapsed: (1.0 / 4.5 ) x 100% = 22%
Length of current scale: 15 cm
Location on current calendar (scale): 15 x .22 = 3.3 cm from left end (point of origin).

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## Figure 2D. A Line Across Time - Worksheet
**(Scale = 15cm line on paper)**

**Names of Team Members:**

**Calculations:**

| Event | Time frame (years ago) | Time elapsed | Units (%) | Line (15 cm) |
|---|---|---|---|---|
| 1 | - | - | -- | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8 | - | - | - | - |
| 9 | - | - | - | - |
| 10 | - | - | - | - |
| 11 | - | - | - | - |
| 12 | - | - | - | - |
| 13 | - | - | - | - |
| 14 | - | - | - | - |
| 15 | - | - | - | - |
| 16 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **17** | - | - | - | - |
| **18** | - | - | - | - |
| **19** | - | - | - | - |
| **20** | - | - | - | - |

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# Figure 4. Table of Useable Units

| Stop | Units (%) | Year (365 day) | Year (days & months) | Month (31 day) | Day (24 hr) | Day (12 + 12 hr) |
|---|---|---|---|---|---|---|
| 1 | 0 | Day 1 | 01 Jan | Day 1 | 0:01 | 0:01 |
| 2 | 22.0 | Day 80 | 23 Mar | Day 7 | 5:16 | 5:16 |
| 3 | 40.0 | Day 146 | 28 May | Day 13 | 9:36 | 9:36 |
| 4 | 55.5 | Day 203 | 24 Jul | Day 18 | 13:19 | 1:19 |
| 5 | 67.7 | Day 247 | 07 Sep | Day 21 | 16:15 | 4:15 |
| 6 | 77.8 | Day 284 | 14 Oct | Day 25 | 18:40 | 6:40 |
| 7 | 86.9 | Day 318 | 17 Nov | Day 27, almost midnight | 20:51 | 8:51 |
| 8 | 88.8 | Day 324 | 23 Nov | Day 28, noon | 21:19 | 9:19 |
| 9 | 90.3 | Day 330 | 29 Nov | Day 28, almost midnight | 21:40 | 9:40 |
| 10 | 90.9 | Day 333 | 02 Dec | Day 29, 4 a.m. | 21:49 | 9:49 |
| 11 | 92.0 | Day 336 | 05 Dec | Day 29, noon | 22:08 | 10:08 |
| 12 | 93.6 | Day 342 | 11 Dec | Day 30, 1 a.m. | 22:28 | 10:28 |
| 13 | 94.5 | Day 350 | 19 Dec | Day 30, 8 a.m. | 22:41 | 10:41 |
| 14 | 95.27 | Day 353 | 22 Dec | Day 31, 1st min | 23:14 | 11:14 |
| 15 | 96.8 | Day 360 | 26 Dec | Day 31, noon | 23:39 | 11:39 |
| 16 | 98.5 | Day 363 | 29 Dec | Day 31, 6 p.m. | 23:51 | 11:51 |
| 17 | 99.95 | Day 365 | 31 Dec | Day 31, last 12 sec | 23:59 | 11:59 |
| 18 | @ | Day 365 | @ | @ | @ | @ |
| 19 | @ | Day 365 | @ | @ | @ | @ |
| 20 | 100 | Day 365 | 31 Dec, midnight | Day 31, midnight | 23:59 | 11:59 |

Curriculum Resources

Figure 5. Calendar Template - One Year

| Su | M | T | W | Th | F | Sa | Su | M | T | W | Th | F | Sa | Su | M | T | W | Th | F | Sa |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **January** | | | | | | | **February** | | | | | | | **March** | | | | | | |
| | | | | | | 1 | | | 1 | 2 | 3 | 4 | 5 | | | | 1 | 2 | 3 | 4 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 27 | 28 | 29 | | | | | 26 | 27 | 28 | 29 | 30 | 31 | |
| 30 | 31 | | | | | | | | | | | | | | | | | | | |
| **April** | | | | | | | **May** | | | | | | | **June** | | | | | | |
| | | | | | | 1 | | 1 | 2 | 3 | 4 | 5 | 6 | | | | | 1 | 2 | 3 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 28 | 29 | 30 | 31 | | | | 25 | 26 | 27 | 28 | 29 | 30 | |
| 30 | | | | | | | | | | | | | | | | | | | | |
| **July** | | | | | | | **August** | | | | | | | **September** | | | | | | |
| | | | | | | 1 | | | 1 | 2 | 3 | 4 | 5 | | | | | | 1 | 2 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 27 | 28 | 29 | 30 | 31 | | | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 30 | 31 | | | | | | | | | | | | | | | | | | | |
| **October** | | | | | | | **November** | | | | | | | **December** | | | | | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | | | | 1 | 2 | 3 | 4 | | | | | | 1 | 2 |
| 8 | 9 | 10 | 11 | 12 | 13 | 14 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 29 | 30 | 31 | | | | | 26 | 27 | 28 | 29 | 30 | | | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| | | | | | | | | | | | | | | 31 | | | | | | |

Curriculum Resources

Figure 6. Calendar Template - One Month

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| - | - | - | - | 1 | 2 | 3 |
| 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | 31 |

Curriculum Resources

Figure 7. Calendar Template - One Day (military time format)

| | |
|---|---|
| 0:00 | 12:00 |
| 0:30 | 12:30 |
| 1:00 | 13:00 |
| 1:30 | 13:30 |
| 2:00 | 14:00 |
| 2:30 | 14:30 |
| 3:00 | 15:00 |
| 3:30 | 15:30 |
| 4:00 | 16:00 |
| 4:30 | 16:30 |
| 5:00 | 17:00 |
| 5:30 | 17:30 |
| 6:00 | 18:00 |
| 6:30 | 18:30 |
| 7:00 | 19:00 |
| 7:30 | 19:30 |
| 8:00 | 20:00 |
| 8:30 | 20:30 |
| 9:00 | 21:00 |
| 9:30 | 21:30 |
| 10:00 | 22:00 |
| | |

| | |
|---|---|
| **10:30** | **22:30** |
| **11:00** | **23:00** |
| **11:30** | **23:30** |

Curriculum Resources

Figure 8. Calendar Template - One Day ("planner" time format)

| | |
|---|---|
| **0:00** | **12:00** |
| **0:30** | **12:30** |
| **1:00** | **1:00** |
| **1:30** | **1:30** |
| **2:00** | **2:00** |
| **2:30** | **2:30** |
| **3:00** | **3:00** |
| **3:30** | **3:30** |
| **4:00** | **4:00** |
| **4:30** | **4:30** |
| **5:00** | **5:00** |
| **5:30** | **5:30** |
| **6:00** | **6:00** |
| **6:30** | **6:30** |
| **7:00** | **7:00** |
| **7:30** | **7:30** |
| **8:00** | **8:00** |
| **8:30** | **8:30** |

| | |
|---|---|
| **9:00** | **9:00** |
| **9:30** | **9:30** |
| **10:00** | **10:00** |
| **10:30** | **10:30** |
| **11:00** | **11:00** |
| **11:30** | **11:30** |

Curriculum Resources

## Figure 9A. Time Flies, No Matter What the Scale - Instructions
**(Scale = Year)**

Many sources on the evolution of organisms on Earth are sadly lacking in topics related to microbes. Further, within microbiology we often fail to integrate our organisms with the arrival of the other species, as well as with specific physiological changes that had dramatic effects on the course of evolution. In this activity, you and the members of your team will examine selected events from the history of this planet. You will convert the historical date assigned to these events into a date within a more familiar time scale to aid you in viewing evolution in its proper scale.

Your team should receive these instructions, a worksheet for recording your calculations, and a list of events in evolution. Please begin by recording the names of your team members on the worksheet. You will also receive a blank calendar covering one year. Your team will be assigned events from evolutionary (and geological) history. Perform the calculations and record the results on the worksheet. Once you complete each conversion from historical time to the appropriate time scale, mark the position of that event on the calendar.

1. First, identify this "Event" on the worksheet.
2. Enter the "Historical date" currently assigned to this event.
3. Subtract the historical date from the age of the Earth (4.5 billion years = 4,500 million years). This "Time elapsed" value represents the length of time that passed between the formation of Earth and the occurrence of this event.
4. Divide the time elapsed value by the total age of the Earth, and multiply by 100%. This "Percent elapsed" value is the proportion of Earth's history that passed before this event.
5. Identify the total time on the calendar (365 days).
6. Multiply the percent time elapsed by the total time on the calendar.
7. Find and mark this point on the calendar.
8. Repeat these steps for each of the events assigned to your team.
9. When completed, review your results.
10. Submit this assignment as directed by your instructor.

An example: Event--first cell.

Historical date: 3.5 BYA
Time elapsed: 4.5 BY – 3.5 BY = 1.0 BY
Percent elapsed: (1.0 / 4.5 ) x 100% = 22%
Length of current calendar: 365 days
Location on current calendar: 365 x .22 = 80.3
*1/3rd through the 81st day (March 23rd).*

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## Figure 9B. Time Flies, No Matter What the Scale - Worksheet
**(Scale = Year)**

**Names of Team Members:**

**Calculations:**

| Event | Time frame (years ago) | Time elapsed | Units (%) | Year (365 day) |
|---|---|---|---|---|
| 1 | - | - | - | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8 | - | - | - | - |
| 9 | - | - | - | - |
| 10 | - | - | - | - |
| 11 | - | - | - | - |
| 12 | - | - | - | - |
| 13 | - | - | - | - |
| 14 | - | - | - | - |
| 15 | - | - | - | - |
| 16 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **17** | - | - | - | - |
| **18** | - | - | - | - |
| **19** | - | - | - | - |
| **20** | - | - | - | - |

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## Figure 9C. Time Flies, No Matter What the Scale - Instructions
**(Scale = Month)**

Many sources on the evolution of organisms on Earth are sadly lacking in topics related to microbes. Further, within microbiology we often fail to integrate our organisms with the others, as well as with specific physiological changes that had dramatic effects on the course of evolution. In this activity, you and the members of your team will examine selected events from the history of this planet. You will convert the historical date assigned to these events into a date within a more familiar time scale to aid you in viewing evolution in its proper scale.

Your team should receive these instructions, a worksheet for recording your calculations, and a list of events in evolution. Please begin by recording the names of your team members on the worksheet. You will also receive a blank calendar covering one month. Your team will be assigned events from evolutionary (and geological) history. Perform the calculations and record the results on the worksheet. Once you complete each conversion from historical time to the appropriate time scale, mark the position of that event on the calendar.

1. First, identify this "Event" on the worksheet.
2. Enter the "Historical date" currently assigned to this event.
3. Subtract the historical date from the age of the Earth (4.5 billion years = 4,500 million years). This "Time elapsed" value represents the length of time that passed between the formation of Earth and the occurrence of this event.
4. Divide the time elapsed value by the total age of the Earth, and multiply by 100%. This "Percent elapsed" value is the proportion of Earth's history that passed before this event.
5. Identify the total time on the calendar (31 days).
6. Multiply the percent time elapsed by the total time on the calendar.
7. Find and mark this point on the calendar.
8. Repeat these steps for each of the events assigned to your team.
9. When completed, review your results.
10. Submit this assignment as directed by your instructor.

An example: Event--first cell.

Historical date: 3.5 BYA
Time elapsed: 4.5 BY – 3.5 BY = 1.0 BY
Percent elapsed: (1.0 / 4.5 ) x 100% = 22%
Length of current calendar: 31 days
Location on current calendar: 31 x .22 = 6.82
*8/10$^{th}$ of the way through the seventh day.*

Curriculum Resources

## Figure 9D. Time Flies, No Matter What the Scale - Worksheet
**(Scale = Month)**

**Names of Team Members:**

**Calculations:**

| Event | Time frame (years ago) | Time elapsed | Units (%) | Month (31 day) |
|---|---|---|---|---|
| 1 | - | - | - | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8 | - | - | - | - |
| 9 | - | - | - | - |
| 10 | - | - | - | - |
| 11 | - | - | - | - |
| 12 | - | - | - | - |
| 13 | - | - | - | - |
| 14 | - | - | - | - |
| 15 | - | - | - | - |
| 16 | - | - | - | - |
| 17 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **18** | - | - | - | - |
| **19** | - | - | - | - |
| **20** | - | - | - | - |

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## Figure 9E. Time Flies, No Matter What the Scale - Instructions
**(Scale = Day)**

Many sources on the evolution of organisms on Earth are sadly lacking in topics related to microbes. Further, within microbiology we often fail to integrate our organisms with the others, as well as with specific physiological changes that had dramatic effects on the course of evolution. In this activity, you and the members of your team will examine selected events from the history of this planet. You will convert the historical date assigned to these events into a time within a more familiar time scale to aid you in viewing evolution in its proper scale.

Your team should receive these instructions, a worksheet for recording your calculations, and a list of events in evolution. Please begin by recording the names of your team members on the worksheet. You will also receive a blank calendar covering one day. Your team will be assigned events from evolutionary (and geological) history. Perform the calculations and record the results on the worksheet. Once you complete each conversion from historical time to the appropriate time scale, mark the position of that event on the calendar.

1. First, identify this "Event" on the worksheet.
2. Enter the "Historical date" currently assigned to this event.
3. Subtract the historical date from the age of the Earth (4.5 billion years = 4,500 million years). This "Time elapsed" value represents the length of time that passed between the formation of Earth and the occurrence of this event.
4. Divide the time elapsed value by the total age of the Earth, and multiply by 100%. This "Percent elapsed" value is the proportion of Earth's history that passed before this event.
5. Identify the total time on the calendar (24 hours).
6. Multiply the percent time elapsed by the total time on the calendar.
7. Find and mark this point on the calendar.
8. Repeat these steps for each of the events assigned to your team.
9. When completed, review your results.
10. Submit this assignment as directed by your instructor.

An example: Event--first cell.

Historical Date: 3.5 BYA
Time Elapsed: 4.5 BY – 3.5 BY = 1.0 BY
Percent Elapsed: (1.0 / 4.5 ) x 100% = 22%
Length of Current Calendar: 24 hours
Location on Current Calendar (Scale): 24 x .22 = 5.28
*1/3$^{rd}$ through the sixth hour of the day (roughly 6:20 a.m.)*

Curriculum Resources

## Figure 9F. Time Flies, No Matter What the Scale - Worksheet
**(Scale = Day)**

**Names of Team Members:**

**Calculations:**

| Event | Time frame (years ago) | Time elapsed | Units (%) | Day (24 hr) |
|---|---|---|---|---|
| 1 | - | - | - | - |
| 2 | - | - | - | - |
| 3 | - | - | - | - |
| 4 | - | - | - | - |
| 5 | - | - | - | - |
| 6 | - | - | - | - |
| 7 | - | - | - | - |
| 8 | - | - | - | - |
| 9 | - | - | - | - |
| 10 | - | - | - | - |
| 11 | - | - | - | - |
| 12 | - | - | - | - |
| 13 | - | - | - | - |
| 14 | - | - | - | - |
| 15 | - | - | - | - |
| 16 | - | - | - | - |
| 17 | - | - | - | - |

| | | | | |
|---|---|---|---|---|
| **18** | - | - | - | - |
| **19** | - | - | - | - |
| **20** | - | - | - | - |

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# Appendix 1. Topics for Great Moments in Microbial Evolution (all activities)

| Era | Epoch / Period | Stop | Events and Topics |
|---|---|---|---|
| - | | | |
| Archean | | 1 | * Formation of planet; composition of early atmosphere; Miller's experiment on prebiotic synthesis: physical and chemical synthesis and condensation into polymers. |
| - | | | |
| Proterozoic | | 2 | * Progenote evolution (RNA-> RNP -> DNA -> cell); fossils from Australia and S. Africa. Anaerobic chemoorganotrophs. Different models of broad phylogenetic divisions: characteristics of modern groups; kingdom vs. domain vs. empire debate and other evolving theories - the ever-changing nature of science. |
| | | 3 | * Depletion of nutrients; selection for more efficiency; anaerobic respiration; photoorganoheterotroph (PS I), photolithoautotrophs (RuBisCo); gene duplication and mutation leads to PS II and production of $O_2$; halobacterial photosynthesis (bacteriorhodopsin vs. bacteriochlorophyll). |
| | | 4 | * Accumulation of $O_2$ (1/100 current levels); development of ozone layer; decrease in UV mutagenesis; increase in oxygen toxicity; aerobic respiration. Summarize relationships of phototrophs (preview plants). |
| | | 5 | * Endosymbiont theory: bacterial origins of mitochondrion and then of chloroplasts, leading to first eukaryotes. |
| | | 6 | * First metazoans; $O_2$ approaches 19%. Phylogeny vs. taxonomy: phyletic, phenetic, financial. Role of Bergey's. |
| - | | | |
| Paleozoic | | | |
| | Cambrian | 7 | * Primitive algae flourish; critical role of primary producers. First appearance of most marine invertebrates. |
| | Ordovician | 8 | * Invertebrates dominant in sea; first appearance of fish and fungi. Does marine environment here have viral DNA at levels of our time? {Origin of viruses: pre-cellular or degenerate, single or multiple, separate origins.} |
| | Silurian | 9 | * First appearance of vascular plants; invasion of land by plants and arthropods. Importance of pigmentation to plant pathogens and airborne bacteria. |

| | | | | |
|---|---|---|---|---|
| | **Devonian** | | 10 | * Fish and trilobites flourish in sea; first amphibians and insects. |
| | **Carboniferous** | | 11 | * Swamp forests (tree ferns and club mosses); amphibians are dominant terrestrial animals. First appearance of reptiles; cost-benefit analysis of internal fertilization; potential for first sexually transmitted diseases (STDs). |
| | **Permian** | | 12 | * First appearance of conifers; end of trilobites. Increase in reptiles, decrease in amphibians. |
| - | | | | |
| **Mesozoic** | | | | |
| | **Triassic** | | 13 | * First appearance of mammals and dinosaurs; larger GI tracts and higher body temperatures lead to increased commensalism, mutualism, and parasitism. Gymnosperm and tree fern forests are predominant terrestrial biomes. |
| | **Jurassic** | | 14 | * Dinosaurs and conifers dominant organisms in terrestrial locations; first appearance of birds. |
| | **Cretaceous** | | 15 | * Alternate hypotheses on extinction of dinosaurs: meteors, ecological collapse, disease. Angiosperms and small mammals diversify, leading to appearance and/or increase of ruminants; gene duplication and mutation of lysozyme with subsequent acid-stable form (exact time unknown). |
| - | | | | |
| **Cenozoic** | | | | |
| | **Tertiary** | | 16 | * Diversification of modern birds. Appearance of placental mammals, required protection during embryonic development from pathogenic agents. Mountain building. |
| | **Quaternary** | **Pleistocene** | 17 | * Glacial cycles; first appearance of genus *Homo.* |
| | | **Recent** | 18 | * Spread of *Homo sapiens*; extinction of many large mammals. |
| | | | 19 | * Exploitation of microbes (fermentation, leavening, acidification in food storage); domestication of animals and plants. |
| | | | 20 | * Observation, identification and (occasionally) control of microbes. |

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# Appendix 2. Correlation of Events with Distances

| Stop | Time frame[a] (years ago) | Time elapsed[b] | Units[c] (%) | Distance[e] (m) {on 500 m} | Distance (m) {on 5 m} |
|---|---|---|---|---|---|
| 1 | 4.5 BYA | 0 | 0 | 0 | 0 |
| 2 | 3.5 BYA | 1.0 Byr | 22 | 110 | 1.10 |
| 3 | 2.7 BYA | 1.8 Byr | 40 | 200 | 2.00 |
| 4 | 2.0 BYA | 2.5 Byr | 55.5 | 277.5 | 2.775 |
| 5 | 1.45 BYA | 3.05 Byr | 67.7 | 338.5 | 338.5 |
| 6 | 1.0 BYA | 3.5 Byr | 77.8 | 389 | 3.89 |
| 7 | 0.59 BYA | 3.91 Byr | 86.9 | 434.5 | 4.345 |
| - | (590 MYA) | (3,910 Myr) | - | - | - |
| 8 | 505 MYA | 3,995 Myr | 88.8 | 444 | 4.44 |
| 9 | 438 MYA | 4,062 Myr | 90.3 | 451.5 | 4.515 |
| 10 | 408 MYA | 4,140 Myr | 90.9 | 454.65 | 4.5465 |
| 11 | 360 MYA | 4,214 Myr | 92 | 460 | 4.6 |
| 12 | 286 MYA | 4,252 Myr | 93.6 | 468.2 | 4.682 |
| 13 | 248 MYA | 4,287 Myr | 94.5 | 472.4 | 4.724 |
| 14 | 213 MYA | 4,287 Myr | 95.27 | 476.4 | 4.764 |
| 15 | 144 MYA | 4,356 Myr | 96.8 | 484 | 4.84 |
| 16 | 65 MYA | 4,435 Myr | 98.5 | 492.8 | 4.928 |
| 17 | 2 MYA | 4,498 Myr | 99.95 | 499.8 | 4.998 |
| 18 | 12,000 YA | @ | - | - | - |
| 19 | 100 YA | @ | - | - | - |
| 20 | Present | 4,500 Myr | 100 | 500 | 5.00 |

[a]Time frame - length of time before present. BYA = billion years ago; MYA = million years ago.

| |
|---|
| [b]Time elapsed - length of time since formation of planet. Byr = billion years; Myr = million years. |
| [c]Units - 5 elapsed. Calculated by dividing Time elapsed for current stop (column 3) by estimated age of Earth (4.5 billion years). |
| d. See Figure @ for a linear representation of the % units elapsed. |
| [e]Distance - # meters from starting site. Calculated by multiplying length of path (500 m) by % for current stop. |
| f. See Figure @ for an example of the geographical presentation. |

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# Appendix 3. Correlation of Events with Modern Calendars

| Stop | Time frame[a] (years ago) | Time elapsed[b] | Units[c] (%) | Year[f] (365 day) | Month (31 day) | Day (24 hr) | Day (12 + 12 hr) |
|---|---|---|---|---|---|---|---|
| 1 | 4.5 BYA | 0 | 0 | Day 1 | Day 1 | 0:01 | 0:01 a.m. |
| 2 | 3.5 BYA | 1.0 Byr | 22 | Day 80 | Day 7 | 5:16 | 5:16 a.m. |
| 3 | 2.7 BYA | 1.8 Byr | 40 | Day 146 | Day 13 | 9:36 | 9:36 a.m. |
| 4 | 2.0 BYA | 2.5 Byr | 55.5 | Day 203 | Day 18 | 13:19 | 1:19 p.m. |
| 5 | 1.45 BYA | 3.05 Byr | 67.7 | Day 247 | Day 21 | 16:15 | 4:15 p.m. |
| 6 | 1.0 BYA | 3.5 Byr | 77.8 | Day 284 | Day 25 | 18:40 | 6:40 p.m. |
| 7 | 0.59 BYA | 3.91 Byr | 86.9 | Day 318 | Day 27, almost midnight | 20:51 | 8:51 p.m. |
| - | (590 MYA) | (3,910 Myr) | - | - | - | - | - |
| 8 | 505 MYA | 3,995 Myr | 88.8 | Day 324 | Day 28, noon | 21:19 | 9:19 p.m. |
| 9 | 438 MYA | 4,062 Myr | 90.3 | Day 330 | Day 28, almost midnight | 21:40 | 9:40 p.m. |
| 10 | 408 MYA | 4,140 Myr | 90.9 | Day 333 | - | 21:49 | 9:49 p.m. |
| 11 | 360 MYA | 4,214 Myr | 92 | Day 336 | - | 22:08 | 10:08 p.m. |
| 12 | 286 MYA | 4,252 Myr | 93.6 | Day 342 | - | 22:28 | 10:28 p.m. |
| 13 | 248 MYA | 4,287 Myr | 94.5 | Day 350 | - | 22:41 | 10:41 p.m. |
| 14 | 213 MYA | 4,287 Myr | 95.27 | Day 353 | - | 23:14 | 11:14 p.m. |
| 15 | 144 MYA | 4,356 Myr | 96.8 | Day 360 | - | 23:39 | 11:39 p.m. |
| 16 | 65 MYA | 4,435 Myr | 98.5 | Day 363 | - | 23:51 | 11:51 p.m. |
| 17 | 2 MYA | 4,498 Myr | 99.95 | Day 365 | - | 23:59 | 11:59 p.m. |
| 18 | 12,000 YA | @ | @ | Day 365 | - | @ | @ |
| 19 | 100 YA | @ | @ | Day 365 | - | @ | @ |
| 20 | Present | 4,500 Myr | 100 | Day 365 | - | 23:59 | 11:59 p.m. |

[a]Time frame - length of time before present. BYA = billion years ago; MYA = million years ago.

[b]Time elapsed - length of time since formation of planet. Byr = billion years; Myr = million years.

[c]Units - 5 elapsed. Calculated by dividing Time elapsed for current stop (column 3) by estimated age of Earth (4.5 billion years).

| |
|---|
| d. See Figure @ for a linear representation of the % units elapsed. |
| [e]Distance - # meters from starting site. Calculated by multiplying length of path (500 m) by % for current stop. |
| [f]Year - day of 365-day year. Calculated by multiplying 365 days by % of current stop. |
| g. See Figure @ for an example of the one year presentation. |
| h. See Figure @ for an example of the one month presentation. |
| I. See Figure @ for an example of the one day presentation. |