ARIZONA STATE UNIVERSITY

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GENERAL STUDIES PROGRAM COURSE PROPOSAL COVER FORM

Courses submitted to the GSC between 2/1 and 4/30 if approved, will be effective the following Spring.

Courses submitted between 5/1 and 1/31 if approved, will be effective the following Fall.

(SUBMISSION VIA ADOBE.PDF FILES IS PREFERRED)

DATE 14 Oct 2013

1. ACADEMIC UNIT: School of Mathematics and Natural Sciences

2. COURSE PROPOSED: BIO (prefix) 113 (number) Dinosaurs (title) 4 (semester hours)

3. CONTACT PERSON: Name: Udo Savalli Phone: 3-3750

   Mail Code: 2352 E-Mail: udo.savalli@asu.edu

4. ELIGIBILITY: New courses must be approved by the Tempe Campus Curriculum Subcommittee and must have a regular course number. For the rules governing approval of omnibus courses, contact the General Studies Program Office at 965–0739.

5. AREA(S) PROPOSED COURSE WILL SERVE. A single course may be proposed for more than one core or awareness area. A course may satisfy a core area requirement and more than one awareness area requirements concurrently, but may not satisfy requirements in two core areas simultaneously, even if approved for those areas. With departmental consent, an approved General Studies course may be counted toward both the General Studies requirement and the major program of study. **(Please submit one designation per proposal)**

Core Areas	Awareness Areas
Literacy and Critical Inquiry–L ☐	Global Awareness–G ☐
Mathematical Studies–MA ☐ CS ☐	Historical Awareness–H ☐
Humanities, Fine Arts and Design–HU ☐	Cultural Diversity in the United States–C ☐
Social and Behavioral Sciences–SB ☐	
Natural Sciences–SQ ☐ SG ☒	

6. DOCUMENTATION REQUIRED.
   (1) Course Description
   (2) Course Syllabus
   (3) Criteria Checklist for the area
   (4) Table of Contents from the textbook used, if available

7. ***In the space provided below (or on a separate sheet), please also provide a description of how the course meets the specific criteria in the area for which the course is being proposed.***

CROSS-LISTED COURSES: ☒ No ☐ Yes; Please identify courses: ______

Is this amultisection course?: ☒ No ☐ Yes; Is it governed by a common syllabus? ______

Roger L Berger
Chair/Director (Print or Type)

Roger L Berger
Chair/Director (Signature)

Date: 10/16/13

Rev. 1/94, 4/95, 7/98, 4/00, 1/02, 10/08

Request for General Studies Designation for:
BIO 113 — Dinosaurs

Course Description: Principles of evolution, ecology, behavior, anatomy and physiology using dinosaurs and other extinct life as case studies. Geological processes and the fossil record. Cannot be used for major credit in the biological sciences. Fee.

Included Documents:

- Course Proposal Cover Form
- Course Catalog Description (this page)
- Criteria Checklist for General Studies SG designation, including descriptions of how the course meets the specific criteria
- Proposed Course Syllabus
- Table of contents (and preface) from the textbook (Fastovsky & Weishampel, 2nd ed.)
- Selected lab handouts and worksheets

Proposer: Please complete the following section and attach appropriate documentation.

ASU--[SG] CRITERIA			
I. - FOR ALL *GENERAL* [SG] NATURAL SCIENCES CORE AREA COURSES, THE FOLLOWING ARE CRITICAL CRITERIA AND MUST BE MET:			
YES	**NO**		**Identify Documentation Submitted**
✓		**1.** Course emphasizes the mastery of basic scientific principles and concepts.	Syllabus; Textbook table of contents; specific lab handouts (see page 5 below)
✓		**2.** Addresses knowledge of scientific method.	Syllabus; see page 5 below
✓		**3.** Includes coverage of the methods of scientific inquiry that characterize the particular discipline.	Syllabus; Lab handouts; see page 6 below
✓		**4.** Addresses potential for uncertainty in scientific inquiry.	Syllabus; see page 6 below
✓		**5.** Illustrates the usefulness of mathematics in scientific description and reasoning.	Syllabus; Lab handouts; see page 6 below
✓		**6.** Includes **weekly** laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.	Syllabus: laboratory schedule; see page 7 below
✓		**7.** Students submit written reports of laboratory experiments for constructive evaluation by the instructor.	Syllabus; Lab worksheets; see page 7 below
✓		**8.** Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth or specificity.	Syllabus; Textbook table of contents; see page 8 below
II. - AT LEAST ONE OF THE ADDITIONAL CRITERIA THAT MUST BE MET WITHIN THE CONTEXT OF THE COURSE:			
✓		**A.** Stresses understanding of the nature of basic scientific issues.	See page 8 below
✓		**B.** Develops appreciation of the scope and reality of limitations in scientific capabilities.	See page 8 below
	✓	**C.** Discusses costs (time, human, financial) and risks of scientific inquiry.	Only to a limited extent

[SG] REQUIREMENTS CANNOT BE MET BY COURSES:
• Presenting a qualitative survey of a discipline.
• Focusing on the impact of science on social, economic, or environmental issues.
• Focusing on a specific or limiting but in-depth theme suitable for upper-division majors.

Course Prefix	Number	Title	Designation
BIO	113	Dinosaurs	SG

Explain in detail which student activities correspond to the specific designation criteria. Please use the following organizer to explain how the criteria are being met.

Criteria (from checksheet)	How course meets spirit (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
1. Course emphasizes the mastery of basic scientific principles and concepts.	The course will emphasize understanding evolutionary principles including natural selection, adaptation, and phylogenetic relationships. Various other topics in animal biology will be explored as well, including basic principles of anatomy and physiology (including the relationship between diet and anatomy, adaptations for flight, and thermoregulation), growth and and development, ecology, and animal behavior (including social behavior, parental care, and sexual selection).	See lecture and lab schedules of syllabus and table of contents of textbook. Labs will specifically address the following: stratigraphy and isotope dating (Lab 3); natural selection (with a simulation experiment), and phylogenetic analysis (Lab 4); Species diversity and community structure (Labs 5-6); allometry and effects of size (Lab 13, though I plan on expanding this lab). In addition, all of the labs focused on diversity ask students to provide adaptive interpretations for morphology and relate the evolution of particular traits to phylogenies. Relevant lab handouts are attached.
2. Addresses knowledge of scientific method.	The basic process of the scientific method is explicitly covered in the lecture portion of the class; the scientific method is applied throughout course as we ask how we our understanding of extinct organisms comes about and address specific controversies.	Week 1 of lecture schedule. Laboratory worksheets will require students to formulate and adaptive and phylogenetic hypotheses. The field trip and followup labs (Labs 5-6) will involve students collecting data to test specific hypotheses about the distribution of fossil marine invertebrates.

Criteria (from checksheet)	How course meets spirit (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
3. Includes coverage of the methods of scientific inquiry that characterize the particular discipline.	This course in is especially well suited for this, since we will frequently ask how we know about various aspects of dinosaur biology. It will include how fossils are dated, how exinct organisms are reconstructed, how we determine evolutionary relationships, how we can determine diet and lifestyles of extinct organisms.	Stratigraphy and dating will be investigated using real and simulated data to determine relative and absolute ages (Lab 3). Phylogenetic thinking (i.e., evolutionary relationships) will be introduced in lecture and Lab 4, and emphasized in all subsequent labs. In Lab 8, students compare tooth measurements of dinosaurs & modern animals to determine probable diets. Relevant lab handouts are attached.
4. Addresses potential for uncertainty in scientific inquiry.	Again, this course is especially well suited for addressing uncertainty, as there is much we don't and can't know. Our views of dinosaurs have changed dramatically in the past decades, even the way they are reconstructed. Comparisons of traditional and more modern views will be made extensively in lecture and to a lesser extent in lab (by for example comparing older and newer models). There will also be substantial emphasis on distinguishing what is conjecture vs. what is known more definitively.	Lecture includes topics such as warm-blooded dinosaurs, social behavior and extinctions where there is much debate. Lab worksheets ask students to consider which aspects of the models are likely to be well-supported by evidence and which are more conjectural. The lab analyzing the field-collected fossils includes very basic statistical analysis for measuring variation and comparisons. Relevant lab handouts are attached.
5. Illustrates the usefulness of mathematics in scientific description and reasoning	Mathematical approaches will be used in phylogenetic analysis, estimating the age of rocks (using half life decay), characterizing community structure (based on fossils collected during field trip), descriptive statistics and basic hypothesis testing (using graphs with standard errors), extrapolating dinosaur mass from scale models, and allometric relationships of body size and other morphological characteristics.	Quantitative approaches are included in Labs 3 (radioisotope problems), Lab 4 (natural selection and phylogenetic analysis), Lab 6 (analysis of fossils collected on field trip), Lab 8 (tooth shape comparisons as they relate to diet), Lab 13 (estimation of dinosaur mass by scaling from models and allometric relationships between body mass and leg size) and Lab 15 (evolutionary changes in primate brain size). Relevant lab handouts are attached.

Criteria (from checksheet)	How course meets spirit (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
6. Includes **weekly** laboratory and/or field sessions that provide hands-on exposure to scientific phenomena and methodology in the discipline, and enhance the learning of course material.	Labs will meet every week, except for one week in which students take a self-guided tour and answer questions at the Arizona Museum of Natural History (which lets them observe complete dinosaur skeletons and other fossils we don't have in lab). Hands on work will involve observations of actual fossils, fossil casts (replicas), field collection of invertebrate fossils (near Payson, AZ), observations of skeletons and skulls of living species, as well as scale models of extinct animals. Even in the 3 labs involving mostly scale models, students will be asked to think phylogenetically and to question the accuracy and validity of aspects of the models.	See "Lab schedule" and "Assignments and grading" sections of syllabus. Techniques include field excavations of invertebrate fossils using defined plots, direct measurements (using calipers) of fossil, fossil replicas, and modern animal specimens (e.g. Labs 5, 6, 8, and 15), as well as opportunities to directly handle various actual invertebrate and vertebrate fossils and replicas.
7. Students submit written reports of laboratory experiments for constructive evaluation by the instructor.	Written reports include a lab report that is completed at home using data collected on the field trip and subsequent lab. All other labs have worksheets that require written answers; these are due either at the end of the lab or in the following lab period.	Syllabus: "Assignments and grading" section. Relevant lab worksheets are attached

Criteria (from checksheet)	How course meets spirit (contextualize specific examples in next column)	Please provide detailed evidence of how course meets criteria (i.e., where in syllabus)
8. Course is general or introductory in nature, ordinarily at lower-division level; not a course with great depth or specificity	Students will need to know only the broadest groups of dinosaurs and other extinct vertebrates, and will not be expected to know detailed classification or dinosaur diversity. Instead, emphasis will be placed on understanding various geological and biological principles as they pertain to dinosaurs. These include plate tectonics and geological cycles, stratigraphy and radioisotope dating, evolution—including natural selection, adaptation, speciation, macroevolution, extinctions, and phylogenies—ecomorphology (how anatomy relates to ecology & lifestyle), anatomical principles, physiology (the warm vs cold blooded debate will be especially emphasized), and behavior. The current textbook is specifically written for a general audience.	See textbook preface and table of contents. Note that only three labs (9-11) emphasize diversity. The 4-5 weeks of lecture devoted to dinosaur diversity is integrated with discussions of biological principles best illustrated by that group of dinosaurs (e.g. the role of sexual selection in the evolution of horned dinosaurs). No previous course work will be required and the course will not count towards any of the majors in the natural sciences. There will not be any comprehensive lab practical exams that test dinosaur identification (only weekly quizzes).
A. Stresses understanding of the nature of basic scientific issues.	See items 3 and 4 above	See items 3 and 4 above
B. Develops appreciation of the scope and reality of limitations in scientific capabilities.	Studying past life has many inherent limitations that will be addressed throughout this course. Students will be expected to consider what aspects of an organism's biology as well supported by evidence and which are mere conjecture.	See item 4 above
C. Discusses costs (time, human, financial) and risks of scientific inquiry.	Will be covered in a limited way in lecture.	Specific topics that touch on this are the time and effort involved in extracting and preparing fossils (lecture photos and video) and dissiculties and costs of the Central Asiatic Expeditions of the 1920s (video).

Arizona State University West Campus

BIO 113: Dinosaurs

Fall 201x

Course Syllabus

Instructor: Dr. Udo M. Savalli
Office: FAB N138A; 602-543-3750
Office hours: [5-6 hours to be determined depending on schedule], or by appointment
Email: udo.savalli@asu.edu or dr.udo@savalli.us
Course web site: http://www.savalli.us/BIO113/ (Also accessible via Blackboard)

Required Text & Supplies: D.E. Fastovsky & D.B. Weishampel 2012. *Dinosaurs: A Concise Natural History*, 2nd ed. Cambridge Univ. Press.
4 Scantron forms: 882-E (100 item)

Description: Principles of evolution, ecology, behavior, anatomy and physiology using dinosaurs and other extinct life as case studies. Geological processes and the fossil record. Cannot be used for major credit in the biological sciences. Fee. *General studies: SG*.

Course Objectives and Expected Learning Outcomes: Dinosaurs are familiar to all even though they have been extinct for 65 million years. In this class we will study what we know and what we don't know about dinosaurs. In particular, we will emphasize the techniques used to study dinosaurs and how we can use modern species to better understand what dinosaurs might have been like. Students will understand the scientific method and how it can be applied to testing hypotheses about long-extinct animals.
Students will understand key scientific principles in evolution, ecology, animal behavior, anatomy, physiology, physics, and geology. Of particular importance are the theories of evolution and continental drift and how they inform our interpretation of the fossil record. Laboratories will use a combination of actual fossils, modern animal analogs, and scale models to study the biology of not only dinosaurs, but also other extinct organisms and evolutionary processes. Students will derive simple phylogenies, and use phylogenetic hypotheses to trace the evolution of particular characteristics. Concepts such as homology and convergent evolution will be stressed. Students will understand the geological cycle and the processes of fossilization and the biases inherent in the fossil record. Students will apply methods of relative and absolute (radioisotope) dating to simulated data to determine the age of fossils. Students will collect data from models to understand allometry and how body size affects various aspects of an organism's biology.

Weekend field trip: A half-day field trip to a fossil collecting site near Payson, AZ will be required. *Closed-toed shoes are required. Transportation to and from the field site is the responsibility of the students*. If you have a medical condition that places you at an increased risk of harm, please bring documentation and suggestions for minimizing risk to the instructor. *Only students enrolled in the course may attend the field trip; friends and family are not permitted* for insurance reasons and to ensure a disruption-free learning environment.

Independent Museum Assignment: In lieu of a regular laboratory, students will also be expected to independently complete an assignment at the Arizona Museum of Natural History in Mesa, AZ. Students can complete this assignment at any time of their choosing prior to its due date. *Transportation to and from the museum is the responsibility of the students*. Students are welcome to bring friends and family members with them to the museum so they may show off their newly gained knowledge.

Assignments & Grading: Grades will be based on a combination of both lecture and laboratory performance.

Lecture exams will be based on the material presented in lecture and your readings (but not laboratory material). Exams will be primarily multiple choice using Scantron forms. Use or accessing of cell phones, PDAs and similar electronic devices is strictly prohibited during exams.

Lab quizzes: Students will take a brief quiz online via Blackboard prior to each laboratory. Each quiz will cover material learned in the previous lab as well as the materials provided for the upcoming lab.

Video worksheets: On occassion, a video may be shown during class. During the video students will be expected to fill out a worksheet. Students missing lecture on a day with a video will not be able to make up the worksheet unless they have an excusable absence.

Laboratory worksheets and problem sets: Students will complete worksheets analyzing and interpreting the results of laboratory investigations. Students are expected to provide statistical summaries of data where appropriate. Depending on the nature of the laboratory, some assignments will be completed entirely in lab and turned in at the end of lab. In other cases, there will be additional analysis and problem sets that students must complete after lab.

Course Grading:
Course grades will be based upon an average score of the following:

3 Exams @ 100 pts each	300
Comprehensive Final Exam	100
3 In-class video worksheets @ 10-15 pts each	40
10 quizzes @ 10 pts each	100
3 lab worksheets/problem sets @ 30 pts each	90
11 laboratory worksheets @ 20 pts each	220
Independent museum worksheet	30
TOTAL	880

Course Grades will be based on the following scale:

98 - 100% —	A+
≥93 - <98% —	A
≥90 - <93% —	A–
≥88 - <90% —	B+
≥83 - <88% —	B
≥80 - <83% —	B–
≥77 - <80% —	C+
≥70 - <77% —	C
≥60 - <70% —	D
0 - <60% —	E

Missed Examinations: Students missing exams or assignments will get a grade of 0 except for exceptional circumstances (such as illness or death in the immediate family; written documentation will be required). If a religious observance or University sanctioned activity prevents students from taking an exam on a specified day, students must make alternative arrangements with the instructor prior to the exam. Unless the student can arrange to take a lecture exam before it is returned to the class (usually the next class period), makeups (for excused absences only) will be given at a day and time determined by the instructor.

Late Assignments: Assignments are due at the *start of class* on the day indicated on the assignment or announced in class. Work turned in after the due date *and time* will be severely penalized (minimum of 10% per day) and will not be accepted at all once assignments have been graded and returned to students. Exceptions may be made for serious illness or other extenuating and documented circumstances, at the instructor's discretion.

Attendance: Attendance is essential to success in this class. If you miss a lecture class it is your responsibility to get notes from a classmate as well as any announcements and handouts (most handouts can be downloaded from the course web site). *Laboratory attendance is mandatory to pass this course!* Due to the nature of these laboratories, missed laboratory sessions **cannot** be made up. Students will not receive credit for any assignments pertaining to the missed lab. Should medical or personal reasons, religous observances, or University-sanctioned activity prevent you from attending the laboratory, a written note from a doctor or other written evidence must be submitted. In such a case the worksheet or other assignment may be accepted or excused (with the course grade prorated). Please contact the instructor ahead of time (or if that is not possible, as soon as possible afterwards), if you must miss a laboratory period. *Students missing more than three laboratories for any reason will not pass this class*. Students arriving late or leaving early will lose points on the relevant assignments.

Classroom behavior: Students that disrupt the class such as by excessive talking may be asked to leave. **Be sure to turn off any cell phones before coming to class**: students whose cell phones ring or who are talking on a cell phone during class may be asked to leave; repeated offenses are subject to additional grade penalties. Students with special circumstances (e.g. sick family member) that requires phone access or leaving early should inform the instructor before class begins. Students are expected to exhibit the same behavior on field trips as they would in a classroom.

Threatening or violent behavior that interferes with a safe learning environment, damages property, or prevents the conduct of the class will not be tolerated. Students that engage in such behavior will be asked to leave and may face withdrawal from the class and their actions reported to the ASU Police and Office of Student Rights and Responsibilities.

Withdrawal Policy: It is the students' responsibility to withdraw themselves from the course should this be necessary. The deadline for unrestricted withdrawal is [November 2].

Incomplete Policy: An incomplete grade (I) will only be given to a student that has completed a substantial portion of the class with a grade of C or higher and who is unable to complete the course requirements due to illness or extenuating non-academic circumstances. Documentation will be required.

Disabilities: Students that need accomodation for disabilities must be registered with the Disability Resource Center and submit appropriate documentation from the DRC.

Cheating will NOT be tolerated! Although students are encouraged to colaborate during laboratories, all take home assignments, exams and quizzes must represent one's own work unless indicated otherwise by the instructor. At a minimum, students should expect a grade of 0 for any assignment in which students violated the code of academic integrity. For more information, students should consult the *ASU Student Academic Integrity Policy* at:
https://provost.asu.edu/index.php?q=academicintegrity

BIO 113 Lecture Schedule

(*Dates Based on Fall 2011*)

Week of:	Topic	Reading*
Aug 19	Course Introduction	1
Aug 22-26	What are dinosaurs? Scientific method; History of dinosaur exploration	1, 14
Aug 29-Sep 2	How fossils are formed; Stratigraphy and the age of rocks	1-2
Sep 7-9	Geological History of Earth; Plate tectonics **Sep 5: Labor Day — No Class**	2
Sep 12-16	Principles of evolution; Understanding evolutionary trees	3
Sep 19-23	Vertebrate anatomy: skeletons and movement **EXAM 1: September 21**	4
Sep 26-30	Vertebrate relationships: dinosaurs and their relatives	4, 15
Oct 3-7	Dinosaur diets; Dinosaur diversity: armored dinosaurs	(75-84); 5
Oct 10-14	The sex lives of dinosaurs; Dinosaur diversity: horned dinosaurs	6
Oct 17-21	Dinosaur diversity: duckbills; raising babies	7
Oct 24-28	**EXAM 2: October 24** Dinosaur diversity: the primitive long-necks	8
Oct 31-Nov 4	Dinosaur diversity: the giants and the problem of being big	8
Nov 7-9	Dinosaur diversity: the meat eaters **Nov 11: Veteran's Day — No Class**	9
Nov 14-18	Feathered dinosaurs and the origin of birds	10-11
Nov 21-23	Dinosaur physiology: the warm-blooded debate **Nov 25: Thanksgiving — No Class**	12
Nov 28-Dec 2	Dinosaur ecology: how they influenced their environment **EXAM 3: December 2**	13
Dec 5	The Cretaceous-Tertiary extinction	15
Dec 12	**FINAL EXAM: 9:50-11:40 pm**	

*Chapters (pages) in Fastovsky & Weishampel 2012. *Dinosaurs: A Concise Natural History*

BIO 113 Laboratory Schedule

(Dates Based on Fall 2011)

Date:	Topic	Assignments
Aug 24	Introduction and laboratory safety	None
Aug 31	Rocks and fossils	In-class worksheet
Sep 7	Estimating the age of rocks	Radioisotope dating problem set
Sep 14	Phylogenetic methods	Phylogenetic analysis problem set
Sep 21	No lab (field trip on following weekend)	
Sep 24	Weekend fossil hunting trip	
Sep 28	Variation and diversity in a fossil community: analysis of field trip data	Invertebrate fossil community worksheet
Oct 5	The vertebrate skeleton	In-class worksheet
Oct 12	Diet and tooth morphology	In-class worksheet
Oct 19	Dinosaur relatives and the dawn of dinosaurs	In-class worksheet
Oct 26	The herbivorous dinosaurs: Ornithischians and Sauropods	In-class worksheet
Nov 2	The meat-eating dinosaurs: Theropods	In-class worksheet
Nov 9	*Archaeopteryx* and the evolution of birds	In-class worksheet
Nov 16	Estimating the mass of dinosaurs	Mass estimation worksheet & problem set
Nov 23	Self-guided tour of the Arizona Museum of Natural History	Independent Worksheet
Nov 30	Human evolution	Estimating brain size worksheet

CONTENTS

PREFACE TO FIRST EDITION: WHY A NATURAL HISTORY OF DINOSAURS?

To the student

Dinosaurs: A Concise Natural History has been written to introduce you to dinosaurs, amazing creatures that lived millions of years before there were humans. Along with acquainting you with these magnificent beasts, reading this book will give you insights into natural history, evolution, and the ways that scientists study Earth history.

What were dinosaurs like? Did they travel in herds? What were the horns for? Did the mothers take care of their babies? Was *T. rex* really the most fearsome carnivore of all time? Were they covered with feathers? How fast could brontosaurus run? Why did dinosaurs get so big? Along with getting answers to these and many other questions, you'll also meet legendary and charismatic dinosaur hunters (including the models for Indiana Jones and *Jurassic Park*'s Dr. Alan Grant) whose expeditions have helped to reveal the dinosaurs' stories from fossils and other fragmental clues left behind in the rocks. *Dinosaurs* will help you think like a scientist, while your knowledge of dinosaurs, natural history, and science grows with each chapter you read.

The book is written by authors who are active dinosaur researchers, with between them more than 50 years of experience teaching. It is illustrated by John Sibbick, one of the world's most famous dinosaur illustrators.

DAVID FASTOVSKY is Professor and Chair of Geosciences at the University of Rhode Island. His interest in dinosaurs started as a child when he read about Roy Chapman Andrews in the Gobi Desert (a story that, naturally enough, graces the pages of the book you are holding). Dinosaurs won out years later when he chose paleontology over a career in music. Fastovsky has carried out fieldwork in far-flung parts of the world, including Argentina, Mexico, the western USA and Canada, and Mongolia. He is known as a dynamic teacher as well as a respected researcher with a focus on the extinction of the dinosaurs, as well as the environments in which they roamed. He has made several television documentary appearances, and was a recipient of the Distinguished Service Award by the Geological Society of America in 2006.

DAVID B. WEISHAMPEL is Professor in the Center for Functional Anatomy and Evolution at The Johns Hopkins University. Recipient of three teaching awards, Weishampel teaches human anatomy, evolutionary biology, cladistics, and, of course, a course on dinosaurs. His research focuses on dinosaur evolution and how dinosaurs function, and he is particularly interested in herbivorous dinosaurs and the dinosaur record of eastern Europe and Mongolia. He is the senior editor of the immensely well-received *The Dinosauria*, and has written or co-written six books and very many scholarly articles. Weishampel has contributed to a number of popular publications as well, including acting as consultant to Michael Crichton in the writing of *The Lost World*, the inspiration for Steven Spielberg's film *Jurassic Park*. In 2011, a special symposium on duck-billed dinosaurs was convened by the Royal Ontario and Royal Tyrrell Museums, Canada, to honor Dr Weishampel's contributions in dinosaur paleontology.

JOHN SIBBICK has over 30 years of illustration experience working on subjects ranging from mythology to natural history and is probably best known for his depictions of prehistoric scenes and dinosaurs. In the first stage of any commission he takes the fossil evidence and consults with specialists in their field and works out a number of sketches to build up an overall picture of structure, surface detail, and behavior. From his base in England he has provided images for books, popular magazines such as the *National Geographic*, and television documentaries, as well as museum exhibits and one-man shows of original artwork. For this book he has provided 194 pieces of original art.

To the instructor

Dinosaurs: A Concise Natural History is a new textbook that uses a particularly attractive vehicle – dinosaurs – to introduce students in the early part of their college careers to the logic of scientific inquiry, and to concepts in natural history and evolutionary biology. The perspective and methods introduced through dinosaurs have a relevance that extends far beyond the dinosaurs, engendering in students scientific logic and critical thinking. The text is a fresh, completely rewritten version of our popular *The Evolution and Extinction of the Dinosaurs* (2005), with enhanced accessibility to students and added features to facilitate its utility for teaching.

A unique conceptual approach

Dino factoids – names, dates, places, and features – are available in zillions of books and websites. We depart from a "Who? What? Where?" approach to dinosaurs, instead building a broad understanding of the natural sciences through the power of competing scientific hypotheses.

Unique among dinosaur textbooks, *Dinosaurs* is rooted in phylogenetic systematics. This follows current practice in evolutionary biology, and allows students to understand dinosaurs as professional paleontologists do. The cladograms used in this book have been uniquely drawn in a way that highlights the hierarchical relationships they depict, ensuring that both the methods and conclusions of phylogenetic systematics remain accessible.

Long experience shows that students come to dinosaur courses with many preconceptions about the natural world; *Dinosaurs* asks them to think in new and revolutionary ways. For example, one of the great advances to come out of the past 20 years of dinosaur research is the recognition that *living birds are dinosaurs*. This somewhat startling conclusion leads to a couple of other counter-intuitive conclusions:

1. Birds are reptiles.
2. Dinosaurs didn't go extinct.

In this and in many other ways, our book will challenge students to reconsider their ideas about science and about their world.

Part I introduces the fundamental intellectual tools of the trade. Chapters 1 and 2 treat geology, the geological time scale, fossils, collecting, and what happens after the bones leave the field. The third chapter, a carefully crafted introduction to the logic of phylogenetic systematics, uses familiar and common examples to acquaint students with the method. Chapter 4 takes students from basal Vertebrata to the two great groups of dinosaurs Ornithischia and Saurischia.

Parts II and III cover, respectively, Ornithischia and Saurischia. The chapters within Parts II and III cover the major groups within Dinosauria, treating them in terms of phylogeny and evolution, behavior, and lifestyle. Ornithischia comes before Saurischia to reinforce the fundamental point that, on the cladogram, the ordering of Ornithsichia and Saurischia within a monophyletic Dinosauria makes no difference.

The phylogenetically most complex of dinosaur groups, Theropoda, is treated last in Part III, when students are best prepared to understand it. Three chapters cover the group: one for non-avian theropods, one on the evolution of birds from non-avian theropods, and one on the Mesozoic evolution of birds, since it was during the Mesozoic that birds acquired their modern form.

Part IV covers the aspects of the paleobiology of Dinosauria, from their metabolism, to the great rhythms that drove their evolution, to their extinction. A special chapter is devoted to the history of dinosaur paleontology. Although commonly introduced at the beginning of dinosaur books as a litany of names, dates, and discoveries, our history chapter – a history of *ideas* – is placed toward the end, so the thinking that currently drives the field can be understood in context. Yet we would cheat our readers if we left out accounts of the dinosaur hunters, whose colorful personalities and legendary exploits make up the lore of dinosaur paleontology; so we've included many of their stories as well.

Features

Dinosaurs is designed to help instructors to teach and to help students learn:

- The book is richly illustrated with many new, especially commissioned, art by John Sibbick, one of the world's foremost illustrators of dinosaurs. These images are exciting for the student to learn from and they effectively highlight and reinforce the concepts in the text. Many pages are also graced by research photographs, generously contributed by professional paleontologists.
- The chapters are arranged so that they present the material in order of increasing complexity and sophistication, building the confidence of the student early on, and extending the sophistication of their learning gradually through the book.
- The tone of the text is light, lively, and readable, engaging the student in the science, and dispelling the apprehension many students experience when they pick up a science textbook.
- "Objectives" at the beginning of each chapter help students to grasp chapter goals.
- Boxes scattered throughout the book present a range of ancillary topics, from dinosaur poetry, to extinction cartoons, to how bird lungs work, to colorful accounts of unconventional, outlandish, and extraordinary people, places, and stories.
- A comprehensive series of "Topic Questions," to be used as study guides, are located at the end of each chapter. The questions probe successively deeper levels of understanding, and students who can answer all of the "Topic Questions" will have a good grasp of the material. Variants of these questions can serve as excellent templates for examination questions.
- A Glossary ties definitions of key terms into the page numbers where the term is used.
- There are two indices: an Index of subjects and an Index of genera that includes English translations of all dinosaur names.

- Appendices are included in certain chapters to introduce material that students may need in order to understand chapter concepts, such as the chemistry necessary to understand radioactive decay, and the basic principles of evolution by natural selection.

Online resources to help you deliver your dinosaur course include:

- Electronic files of the figures and images within the book.
- Lecture slides in PowerPoint with text and figures to help you to structure your course.
- Solutions to the questions in the text for instructors.

Supplemental Documentation For Bio 113 SG Designation

This document contains selected Lab Handouts and Lab Worksheets in support of General Studies Natural Sciences (SG) classification for BIO 113. These were used for LSC 294 (Special Topics: Dinosaurs). I have only included those labs and worksheets that specifically document specific criteria on the Natural Sciences (SG) checklist, rather than the entirety of the course.

Contents:

Lab 3 — Aging Rocks

Introduction.

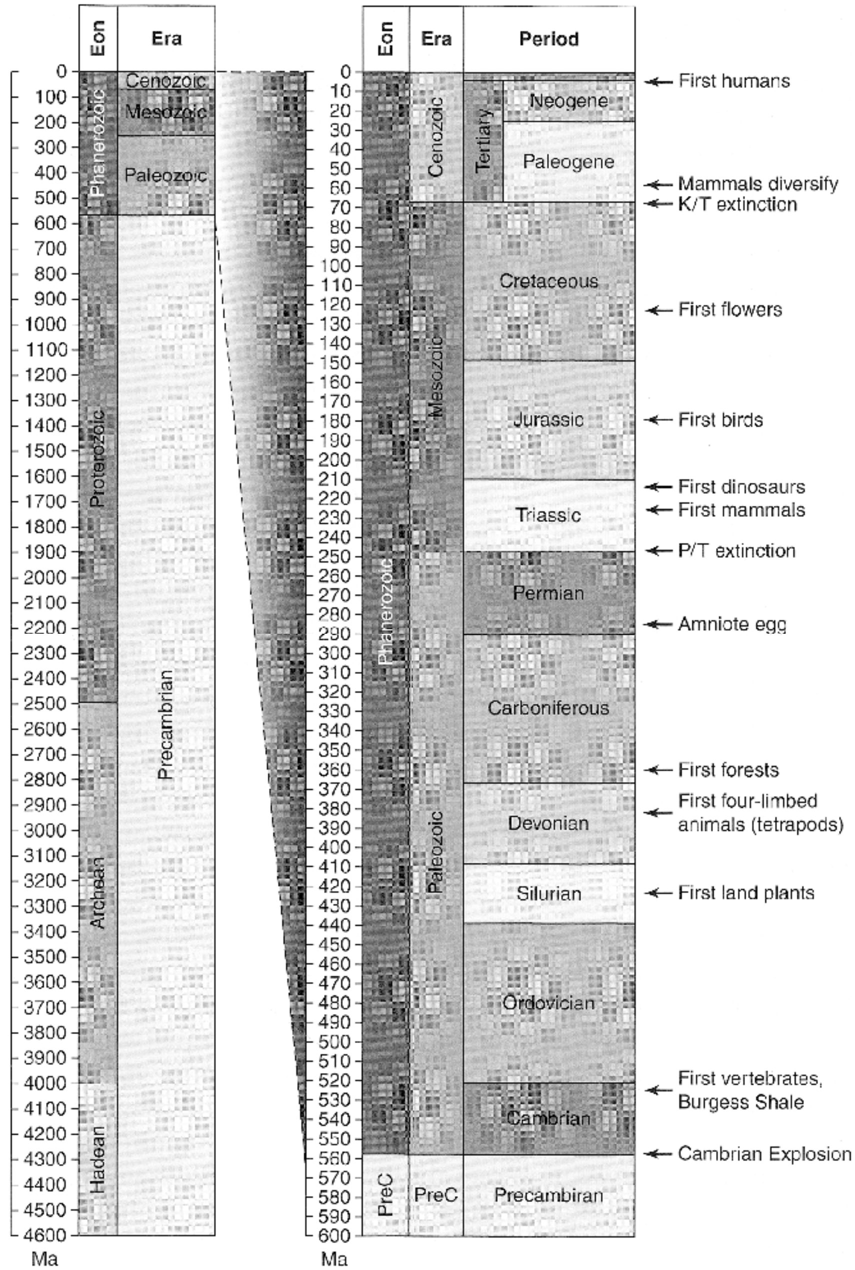
As scientists began to study the earth and fossils in the 18th and 19th centuries, it was noticed that rocks often formed layers (**strata**) of different types, and that certain fossils were often specific to particular layers of rocks. The study of such layering is called **stratigraphy**. The key implication of this layering of fossils is that different fossils are of different ages. Thus, the layering of rocks and their fossils gives a picture of the history and evolution of life. To understand this history, it is important to know how old fossils are. There are two types of dating in use. **Relative dating** determines the chronological sequence of sediments and fossils, that is, which are older and which are younger, while **absolute dating** establishes the actual age, in years, of particular layers of rock. Historically, relative dating was established long before we were able to determine the age of rocks, and remains the basis for naming the geological time periods.

As geologists studied these layers of rocks and fossils, they noticed that there were times when there were abrupt and widespread changes in the kinds of fossils present. This enabled them to begin to categorize geological time into eons, eras, periods, epochs, and so forth. It has only been in the early to mid 20th century, with the development of radiometric dating, that it has been possible to assign dates to these time periods.

Geologists divide the history of earth first into four **eons** (Table 1). The **Hadean** represents the earliest part of Earth's history, before we have evidence of life. Next is the **Archean** eon, from 3.8 to 2.5 billion years ago, in which life consisted of very simple organisms and oxygen was still scarce. The **Proterozoic** eon covers relatively simple organisms, but the presence of oxygen and more complex cells. Finally, the most recent eon is the **Phanerozoic**, which covers the time when complex animal life was abundant, beginning 540 mya (million years ago). Everything prior to the Phanerozoic is sometimes simply lumped together as the "Precambrian."

The Phanerozoic eon is subdivided into three **eras**: the **Paleozoic**, from 540 to 245 mya, the **Mesozoic**, from 245 to 65 mya, and the **Cenozoic**, which extends into the present. Dinosaurs (excluding birds) existed only in the Mesozoic era. Each era is further subdivided into periods. The Mesozoic era, for example, is subdivided into the **Triassic**, **Jurassic**, and **Cretaceous** periods. Periods can be further subdivided into **epochs**. Except during the Cenozoic, epochs are usually just named **early**, **middle**, and **late** (or **lower**, **middle**, and **upper**). Epochs are subdivided into **stages**. On a more regional level, particular layers of rocks that share common characteristics and of the same age are called **formations**.

Figure 1. *The geological time scale.*



Relative Dating.

Relative dating relies on the natural layering, or stratification, of rocks. The oldest rocks will be at the bottom, with the newer layers deposited on top of the older layers. The position within a series of layers can determine the age of a layer of rock relative to the other layers. By itself, this method, called **lithostratigraphy**, only allows for the relative ages of fossils from a single location, although sometimes individual layers of rock can be recognized and followed for up to 100s of miles.

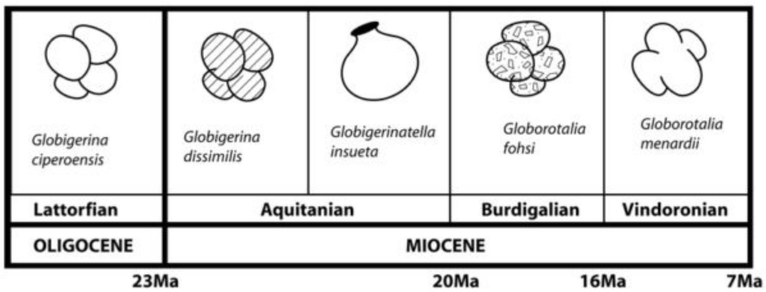
To compare (correlate) the ages of distant sites, geologists use **indicator fossils**. These are distinctive, abundant organisms that are widespread (often in marine environments) and that change quickly over time. The presence of the same indicator fossils in rocks at two different locations indicates that the rocks are of the same age. This method is called **biostratigraphy**. While any kind of fossil can be used as an indicator, the most useful are often small (often microscopic) marine organisms (such as diatoms, conodonts, etc.), pollen and other plant parts, and the teeth of small mammals. Biostratigraphy can indicate the relative age of rocks even from different areas of the globe but does not provide information about the absolute age of the rocks.

Exercise 1: Biostratigraphy and Geological Time Scales.

1. You will work in groups of 2-3 students for this exercise. Each group should occupy their own lab bench.
2. Obtain a set of 24 sheets that each illustrate a schematic view of selected strata from four regions: Europe (France, Germany, Russia), Great Britain (England and Wales), Eastern North America (New York to the southern Appalachians) and Western North America (Texas to South Dakota), as well as location and time period labels. These sheets represent key geological strata described from the late 1700s into the very early 1900s.
3. Begin by placing the four location headings at one end of the lab bench. These will represent the 'top' of the four location columns of your geological chart. Europe and Great Britain should be on one side of the bench, with the United States on the other side.
4. Now begin placing the sheets in their geological sequence, beginning with Europe and Great Britain. You can place sheets adjacent to one another if the lower strata of one sheet contains the same fossils as the upper strata of the sheet below. In this way, you can chronologically link strata from different locations. If strata do not have linking fossils, you should not connect them, as there may be a gap or you may have the wrong sequence. Use the British strata (aligned by shared indicator fossils) to help span the gaps in the European strata.
5. For the American strata, use shared fossils (indicator fossils) to align them horizontally with their corresponding European strata. Note that there may be gaps in the sequences of strata.
6. Determine the geological eras and periods represented by the strata. Note that historical descriptions on the back of the European and some British sheets will give clues to the names of the time periods they represent.
7. Once you have successfully completed your geological strata chart, have your instructor check it.

Exercise 2: Interpreting a Stratigraphic Sequence.

1. The diagram at right illustrates the stratigraphy of fossils of foraminiferans—tiny single-celled organisms with distinctive shells—from the Oligocene to Miocene epochs (of the Cenozoic Era). Some of the foraminiferans and the time intervals (stages) they indicate are shown in the chart below.



2. Using colored pencils, draw horizontal lines across the stratigraphic sequence at the right to indicate the boundaries between the different stages (Lattorfian, etc.).

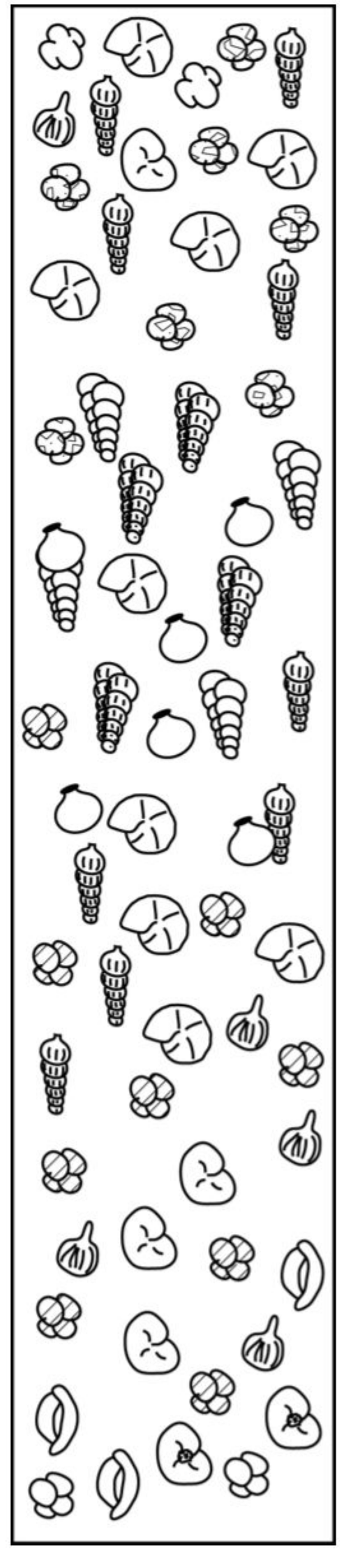
3. During which stage, the Aquitanian or Burdigalian, were sediments deposited more rapidly ? (Hint: the rate at which sediments are deposited determines the thickness of the strata.)

4. During which stage(s) was *Bolivina marginata* (illustrated at left) present?

5. Do any of the foraminiferans show a gap in their distribution (i.e., have a period in which they are absent between times when they are present)? If so, sketch any that do.

6. What might be a biological (not geological) reason to explain such a gap in distribution?

Figure 2. *Stratigraphy of a marine deposit. Total height is 10 m.*



Absolute Dating: Basics of Radioactive Decay.

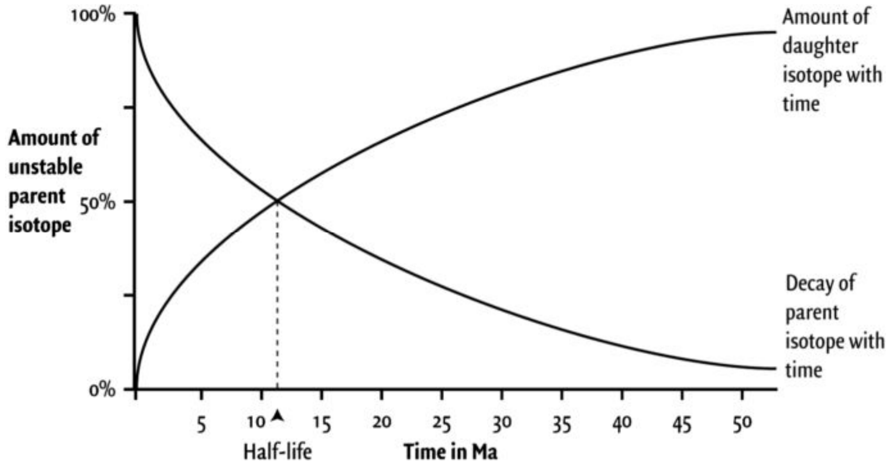
Absolute or **numerical dating** or **chronostratigraphy** involves the use of radiometric dating: the determination of the age of the rocks, in years using the amounts of various radioactive isotopes.

To understand this technique, we must first cover some background. All matter on earth is composed of fundamental units called **atoms**. Each atom has a nucleus composed of one or more **protons** and some number of **neutrons**, each with the same weight of 1 atomic unit. These are surrounded by very tiny electrons. There are 92 naturally occurring types of atoms; each type is referred to as an **element** (there have been an additional 26 or so elements synthesized briefly in particle accelerators but not seen in nature). All matter is thus composed of various combinations of these elements. For example, water, H_2O, is composed of two elements: hydrogen and oxygen (with two hydrogen atoms attached to one oxygen atom). The elements differ from one another by the number of protons in the nucleus of the atom. For example, carbon always has 6 protons and oxygen always has 8 protons.

Isotopes are atoms of the same element (that is, they have the same number of protons), but differ in the number of neutrons. Unlike protons, neutrons do not have much effect on the chemical properties of atoms, but they do affect their weight. For example, the element carbon (C) has 6 protons (by definition), and can have 6, 7, or 8 neutrons. Thus, there are three possible isotopes of carbon: ^{12}C, ^{13}C, and ^{14}C (note that the atomic mass—the combined number of protons and neutrons—is written as a superscript before the symbol for the element). Some isotopes are stable atoms, while others are unstable: they undergo a process of **radioactive decay** in which they release energy and subatomic particles. As they decay, atoms can release neutrons or protons or convert protons into neutrons and vice versa. Thus, radioactive decay results in a change their atomic mass and/or a change into a different element. For example, ^{12}C is a stable isotope of carbon and does not decay, but ^{14}C is a radioactive isotope and decays into ^{14}N (nitrogen) by converting one of its neutrons into another proton (thus giving it 7 protons and making it a nitrogen atom). ^{14}N is stable and does not undergo any further decay.

Radioactive decay is useful for dating rocks because radioisotopes decay at known rates. The decay of individual atoms is actually a random process with a certain fixed probability. Thus, a more or less constant *proportion* of atoms will decay in any given time period, rather than a fixed amount. If there are fewer atoms to begin with, fewer atoms will decay. This rate of decays is described as the **half-life**, the amount of time it takes one half of the isotope to decay (this is a constant, and is independent of how much isotope one starts with) (Figure 3). The half-life of ^{14}C is is 5730 years. If one starts with 10 g of pure ^{14}C, after 5730 years there will be 5 g remaining, and after a total of 11,460 years there will be 2.5 g remaining. After this time, one would have 7.5 g of ^{14}N

Figure 3. *Isotope decay curves. As the parent (starting radioisotope) decays, it decreases in amount at the same rate as the daughter product isotope increases. This is Fig. 2.1 of your text.*



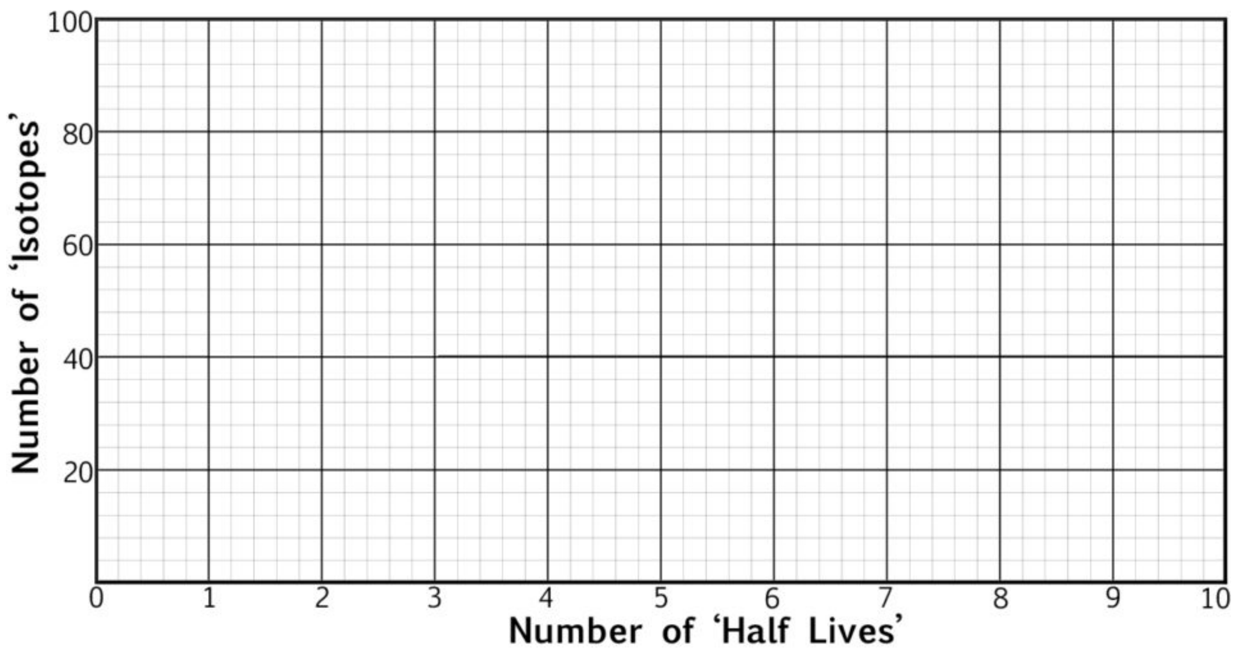
instead. If the starting amount and current amount of isotope, as well as its half-life, are known, these can be used to determine the date when the isotope became part of the mineral (or organism for ^{14}C). For example, if the ratio of ^{14}C relative to the amount of ^{12}C (typically around 1 ^{14}C atom per 1 trillion carbon atoms) in a sample of old wood is ⅛ of the normal atmospheric amount (New ^{14}C is generated at a roughly constant rate in the upper atmosphere by cosmic rays interacting with nitrogen atoms), then the age of the wood is approximately 3 half-life periods (½ of ½ of ½), or about 17,000 years since the tree died and stopped taking up carbon.

Exercise 2: Radioactive decay simulation.

1. Complete the following simulation in class. *Do not leave until it has been checked by your instructor*. You may work with a lab partner
2. We will simulate the radioactive decay of atoms using coins. Heads will represent the parent radioisotope, and tails will represent the stable product. Begin with 100 (theoretical) coins that are all heads (radioisotopes). You will flip the coin to determine if it has undergone "radioactive decay." Since each coin has a 50% chance of coming up tails, you would expect about half of each set of coins to "decay." Each bout of coin flipping thus represents one half life.
3. Flip each of these coins once, noting if the result is head or tail. (You will probably not have 100 coins available, so instead just use one coin that you flip 100 times, but record the number of heads and tails for the first half life period.
4. Any coins that came up tails will remain tails (since these represent a stable isotope). For each head that you flipped, flip those coins again, and once again note the number of heads and tails.

5. Repeat the process for 8 more generations (or until you have no more heads), flipping only the heads again.
6. Calculate the *cumulative* number of tails by adding the number generated in the current generation by the total generated in the previous generation (if you have no more heads, the the cumulative number of tails should be 100).
7. In the graph below, plot the change in the number of parent radioisotopes (heads) and number of stable daughter isotopes (tails) per half lives.

# of Half lives	# Heads (parent radioisotopes)	# Tails (stable daughter isotopes	Cumulative number of tails
0	100	0	0
1			
2			
3			
4			
5			
6			
7			
8			
9			



Absolute Dating: Calculating the Age of Rocks.

Usually it is not practical to figure out how many halvings are involved to reach a particular concentration since it will often not be a whole number, and in fact may be much less than 1 for isotopes with long half-lives. Instead, we will calculate time using an inverse growth equation (this is similar to a compounding interest problem, but with declining proportions):

(equation 1) $$t = \frac{1}{\lambda}\ln\left(\frac{D}{P}+1\right)$$

where t is the time since the mineral's formation from magma or lava, λ is the decay rate, **ln** is the natural logarithm, D is the amount of 'daughter isotope,' that is currently present (has accumulated), while P is the amount of 'parent isotope,' that remains. The decay rate is the probability that a particular atom of the isotope will undergo radioactive decay in one year. It is inversely related to the half life: the higher the decay rate, the shorter the half life.

The isotopes of value depend on the age of the rocks in question. For dinosaur-containing rocks, ^{14}C is not suitable because its half-life is too short. Not enough is left to detect after such a long time. Furthermore, it is relatively uncommon to have the original carbon remain in bones and other fossils of that age. A number of other isotopes do have suitably long half-lives and are elements regularly found in minerals (Table 2).

Table 2. *Radioisotopes commonly used for dating, including the half life and decay rate per atom per year and the range of time over which it can be used.*

Parent Isotope	Daughter Product	Half Life (years)	Decay rate per year[1]	Useable range (years)
Carbon, ^{14}C	Nitrogen, ^{14}N	5730	1.21×10^{-4}	<60,000
Potassium, ^{40}K	Argon, ^{40}Ar	1.3 billion	5.33×10^{-10}	>100,000
Uranium, ^{234}U	Thorium, ^{230}Th	250,000	2.77×10^{-6}	>1 million
Uranium, ^{235}U	Lead, ^{207}Pb	0.7 billion	9.90×10^{-10}	>100 million
Uranium, ^{238}U	Lead, ^{206}Pb	4.5 billion	1.54×10^{-10}	>100 million
Thorium, ^{232}Th	Lead, ^{208}Pb	14 billion	4.95×10^{-11}	>300 million
Rubidium, ^{87}Rb	Strontium, ^{87}Sr	49 billion	1.41×10^{-11}	>100 million

For most of these radioisotopes, their original concentration at the time the mineral formed is unknown. However, the resulting decay product would not have been pre-

[1] Very large or very small numbers are best represented in scientific notation, in which a number is multiplied by 10 raised to a certain power. For example, $100 = 10^2$. To convert scientific notation to normal numbers, simply move the decimal point to the right by the exponent number of places, or to the left if the exponent is negative. Thus, 6,200,000 can be written 6.2×10^6 and 0.0043 can be written as 4.3×10^{-3}. To type scientific notation in *MS Excel*, use E+ to represent x10. Thus, 1.5×10^5 would be typed as 1.5E+5

sent in the mineral at the time it formed, so it can be used to count the amount of the isotope that has already decayed. For example, the radioisotope of potassium, ^{40}K, decays into argon, ^{40}Ar with half life of 1.3 billion years. Argon is a noble gas, meaning it does not react with other elements and would not be chemically bonded within minerals. Any ^{40}Ar present in a mineral would be the result of radioactive decay that took place after the rock cooled to a solid (since when liquid, any argon that is formed would easily escape). The ratio of ^{40}K to ^{40}Ar can thus be used to measure how much radioactive decay has taken place.

One major limitation of radioisotope dating is that it measures the time since the formation of igneous (and in some cases, metamorphic) rock that established the elements present in the mineral. This means that sedimentary rocks usually cannot be dated directly. Radioisotopes applied to sedimentary rocks would give the date when the parent material, the igneous rock, was initially formed, which could be hundreds of millions of years before it broke down through erosion to form sediments. Therefore, except for fossils preserved in volcanic ash sediments (or sediments with other types of volcanic inclusions), we cannot date the sediments of fossils directly, but have to date the nearest layers of igneous rock to put upper and lower limits on the sedimentary dates.

Exercise 3: Radioisotope problems.

1. Complete the following problems in class. *Do not leave until they have been gone over or checked by your instructor*. You will then need to complete the problem set on your own time.

2. If your calculator does not do natural logarithms (ln), then you can use *MS Excel* to calculate them. In any cell, type:

   =LN(#)

   except instead of #, type the number you want to take the natural log of, or the address of the cell that contains the number.

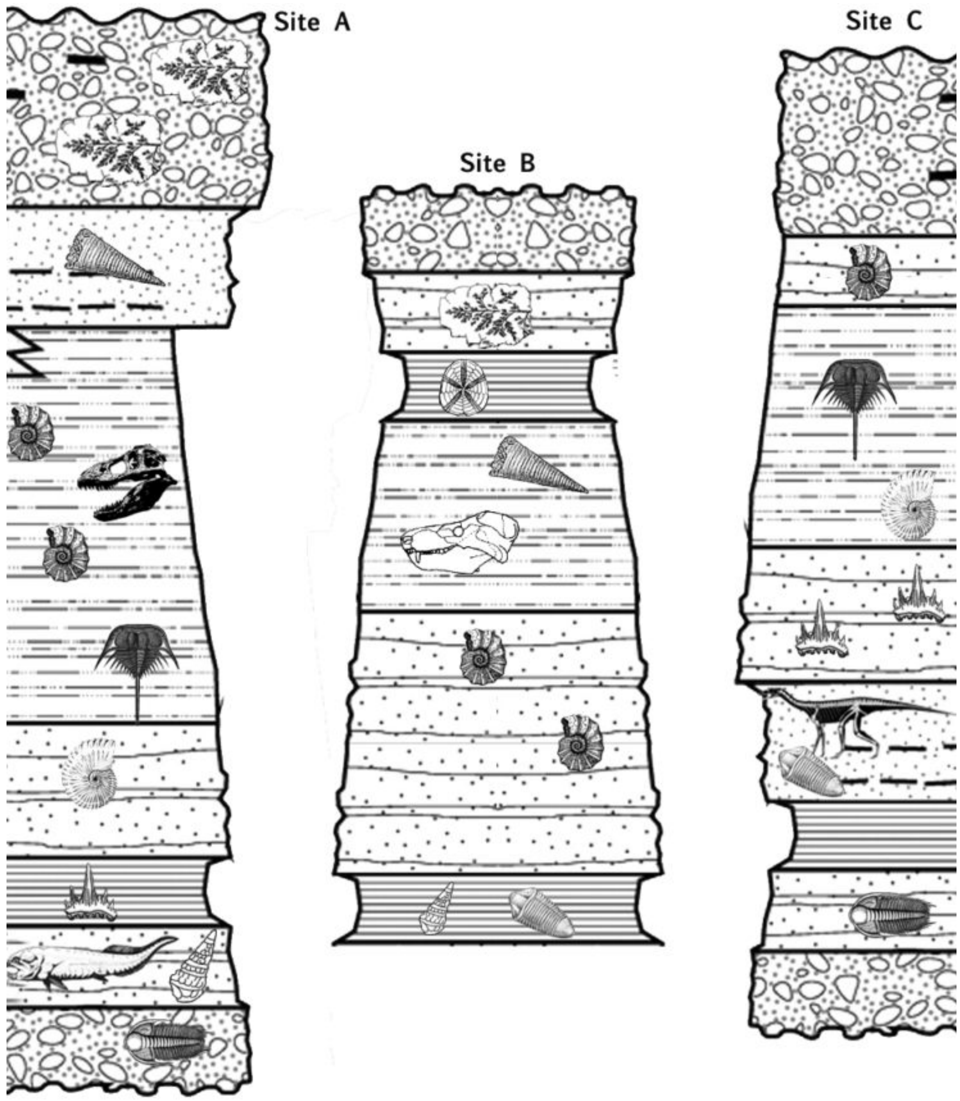
3. A sample of igneous rock contains 350,000 uranium ^{238}U atoms and 23,000 Lead ^{206}Pb atoms. Using equation 1 and the data in table 2, calculate the age of this sample. *Show your work*.
   Show your work by setting up the equation 1 and then substituting the appropriate numbers (you do *not* have to show long hand arithmetic).

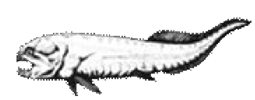
4. Instead of measuring the actual number of atoms (which is often impossible), it is common to simply measure the ratio of the amount of daughter isotope relative to the parent isotope. This ratio can then be substituted for $^{D}/_{P}$ in equation 1. If a mineral sample has exactly equal amounts of ^{40}K and ^{40}Ar then exactly ½ of the potassium has undergone decay (assuming all of the Argon is the product of the decay of ^{40}K). Verify the half life of ^{40}K using the inverse growth equation and yearly decay rate given in Table 2. If the amount of ^{40}K and ^{40}Ar are equal, then $^{D}/_{P} = 1$. *Show your work.*

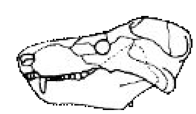
Lab 3 Fossil Dating Problem Set

Part 1. Relative Dating.

1. At right are illustrated strata from three different locations along with some of the indicator fossils found in each. For each pair of major fossils shown below, circle to indicate if the fossil on the right is of the same age, younger, or older than the one on the right.



 *is older than* / *same age as* / *younger than* 

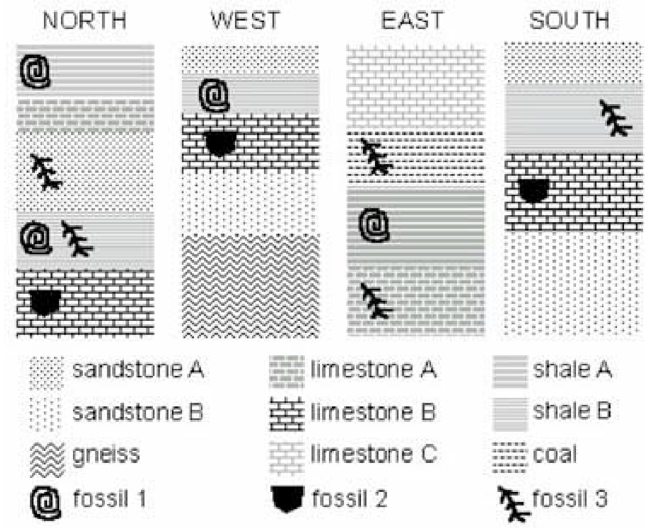
 *is older than* / *same age as* / *younger than* 

 *is older than* / *same age as* / *younger than* 

 *is older than* / *same age as* / *younger than* 

 *is older than* / *same age as* / *younger than* 

2. Four outcrops of rock are examined in different locations of a state. The rock types and the fossils they contain are illustrated in the adjacent diagram. Which fossil would be the best choice to use as an index fossil for these rocks? Explain your answer.



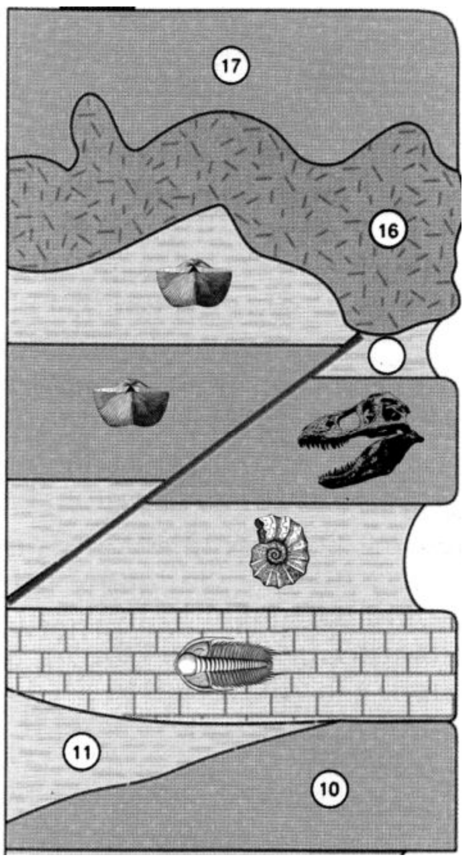
Part 2. Half Life.

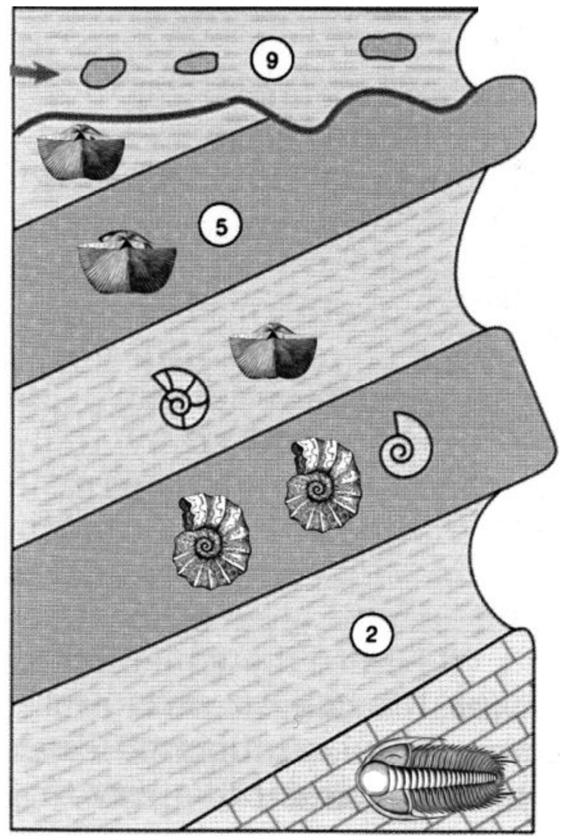
3. If 12.5 g of ^{235}U remain after 2.8×10^9 years, how much of the radioactive isotope was in the original sample? You will need to know the half-life of ^{235}U, given in Table 2 of the lab handout.

4. Uranium-234, ^{234}U, has a half-life of 250,000 years. How much of an 848 g sample of ^{234}U would be left after 1.5 million years?

Part 3. Absolute Dating.

5. The diagram below left shows a number of strata, including one which contains the skull of *Tyrannosaurus*. A second location some distance away is shown at the right, which contains several additional fossils. Layer 16 at the left location is basalt that contains a ^{207}Pb to ^{235}U ratio (D/P) of 0.0612. Layer 2 at the right location contains volcanic ash that has an ^{40}Ar to ^{40}K ratio (D/P) of 0.043. Layer 9, also the right location, is a granite that contains 1.74×10^{96} times as much ^{230}Th as ^{234}U.





A. Provide a date for each of the igneous rock layers using the appropriate radioisotope decay data from the lab handout (*show your work*):

Layer 16:

Layer 9:

Layer 2:

B. Based on the stratigraphic data illustrated in the figures and your calculations of the geological age of several rock layers, give the **minimum** and **maximum** possible ages of the *Tyrannosaurus* skull.

C. Which methodology (biostratigraphy, chronostratigraphy, or lithostratigraphy was used to determine the age of the sedimentary rock layer **below** the *Tyrannosaurus*?

Lab 4 — Evolution & Phylogenetic Analysis

Part I — Natural Selection

One of Charles Darwin's most important contributions was proposing a mechanism for producing evolutionary change. Darwin noted that all animals can produce far more offspring than can be supported in an environment with limited resources, so there must be a "struggle for existence" as organisms compete for resources. Given that not all individuals in a population are alike, some individuals likely have characteristics that make the more successful at surviving or reproducing, that is, they are more "**fit**." This "survival of the fittest" is the essence of **Natural Selection** and a cornerstone to understanding evolution. Traits that are produced by natural selection are called **adaptations**. Adaptations are traits that were beneficial to an organism's ancestors, and usually are still beneficial to that organism.

Exercise 1: Simulation of Natural Selection.

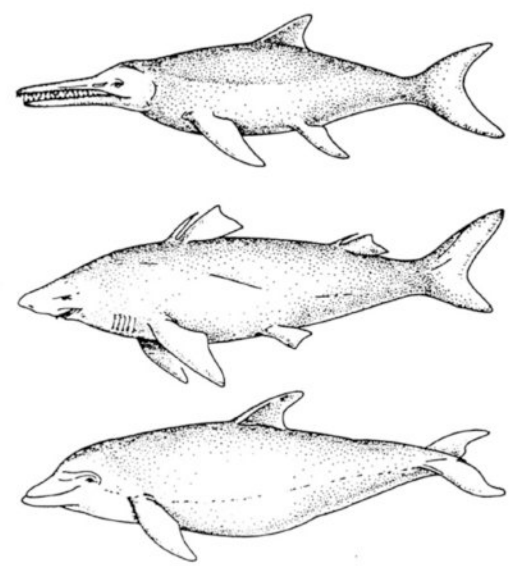
1. To illustrate the process of natural selection, we will perform a simulation of predation over several generations. Students will work in pairs.
2. The environment will be simulated using pieces of multicolored fabric that reflects the complexity of many real environments. Each group should spread one such piece of fabric flat on their lab bench.
3. The prey are a small, flat, round insect, represented by disks of colored paper. The prey species is quite variable in color. Each group should obtain 5 vials of prey, each of a different color.
4. Select 10 prey items from each color (thus 50 items total) and mix them together in the small dish provided. Randomly spread them out over your colored fabric.
5. One student in the group will be a predatory insect-eating dinosaur. Unlike what is usally shown on TV, it is *not* necessary to roar to scare your prey before attacking. Use the forceps to capture prey one at a time and place the captured prey in the dish. While one student captures prey, the other should keep track of the number of prey captured.
6. Continue capturing prey as quickly as you can until you have captured 25 prey.
7. You will need to allow the prey to reproduce so you don't drive them to extinction. Color pattern is heritable, so each prey insect will produce one offspring that are the same color as the parent (these insect reproduce asexually).

8. Since only those insects that were not eaten can reproduce, you must count the number of each color left alive on your fabric. Add an equal number of the same colors to your fabric to represent reproduction and increase the population back to 50.
9. Repeat the predation of 25 prey, followed by reproduction, for a total of 3 generations.
10. Record the results and answer the questions on the worksheet for this lab.

Part II — Phylogenetic Analysis

One of the first questions that is asked when a new dinosaur is discovered is 'how is it related to other dinosaurs'? The answer to that question can allow us to fill in missing information and understand how dinosaurs evolved. Much of the study of dinosaurs is preoccupied with understanding their relationships.

Fig. 1. *Convergent evolution: from top to bottom: ichthyosaur, shark, and dolphin.*



The evolutionary history of a group of organisms can be represented by a branching **phylogenetic tree** (or **dendrogram**). Because closely related organisms will probably have more characteristics in common than will more distantly related organisms, it might seem that the best way to unravel phylogenetic history would be to group together those organisms that are most similar to each other. An approach based on overall similarity has some drawbacks, however. Most importantly, not all similarity is due shared ancestry. **Convergent evolution**, the independent evolution of similar characteristics due to similar environments, can produce close similarities in otherwise only distantly related organisms. Consider, for example, ichthyosaurs (extinct marine reptiles), sharks (cartilaginous fish), and dolphins (mammals) (Fig. 1). Their similar streamlined shapes, dorsal, pectoral and tail fins are the result of convergent evolution since they each evolved from very different ancestors (a land reptile, a primitive fish, and a mammal, respectively). Their superficial similarity does not indicate that they are closely related.

The primary modern method by which phylogenetic trees are derived is called **cladistics**. The goal of cladistic analysis is to determine the true sequence of branching that occurred during evolutionary history. It does this by only using those traits that provide useful phylogenetic information. A phylogenetic tree that is derived through cladistic analysis is called a **cladogram**.

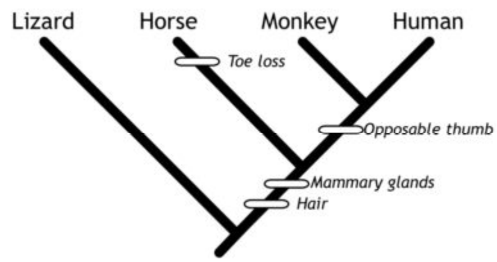
How do we decide which characters are phylogenetically informative? We start by trying to eliminate similarities due to convergent evolution. Such traits may be identified by differences in how they develop or in their internal structure. The skeletal structure of a shark's fin is very different from that of either the dolphin's or ichthyosaur's fin. Similarly, although dolphin and ichthyosaur tails have a similar shape, dolphin flukes are flattened horizontal and move vertically, while ichthyosaur tail fins are vertically flattened and move laterally.

But convergent traits are not the only types of similarities that can lead to incorrect conclusions. Consider, for example, the phylogenetic relationships among four groups: lizards, monkeys, humans, and horses. The first three all have five toes in their hind foot, while horses have only a single toe. Does this mean that lizards and humans are more closely related than are humans and horses? No: the presence of five toes in the foot is an **ancestral** (or primitive) trait; the earliest amphibians also had five toes in their hind foot, and lizards, monkeys, and humans have simply retained this ancestral number of toes. Horses, meanwhile, have lost all but one of their toes during the course of their evolutionary history.

In cladistic analysis, only **derived** traits, that is, those traits that first originated within the group of interest, are used. How do we determine if a trait is ancestral or derived? The best method is to use an **outgroup**, a closely related species that is known to be outside the group of interest. In the above example, amphibians would be an outgroup because we know (based on other evidence) that they are outside of the group that contains lizards, monkeys, horses and humans. In other words, the last common ancestor of these species and lizards goes even further back. Any trait that is shared with the outgroup is considered to be ancestral for the group of interest (called the ingroup), while the alternate version not shared with the outgroup is considered to be derived. Thus the presence of five toes is ancestral, since that trait evolved even before the common ancestor or the species being studied (as indicated by its presence in the amphibian outgroup). The reduction in the number of toes in horses is derived since it happened after the common ancestor of all four species being studied.

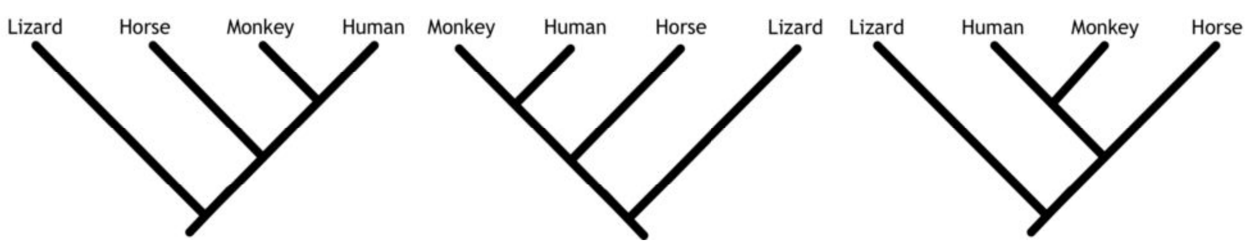
In summary, cladistics doesn't rely on simple similarity, but instead is restricted to using shared traits that are **homologous and derived**. Homologous traits can often (but not always) be recognized by similar underlying structures and development. Derived traits are identified by using outgroups: the derived state is the one that is different from the outgroup.

To determine the relationships of horses, monkeys, and humans, suitable derived homologous traits include the presence of hair, mammary glands, opposable thumbs, and reduction of toes, none of which are found in amphibians. Monkeys and humans are united because they share the derived character of the opposable thumb, found in neither in horses nor lizards. This allows us to group them together in a **clade**. Similarly, monkeys, humans and horses all share mammary glands and hair, allowing these three species to be united into a clade as well. Note that clades can be nested within each other. From these traits, we can construct the following **cladogram**:

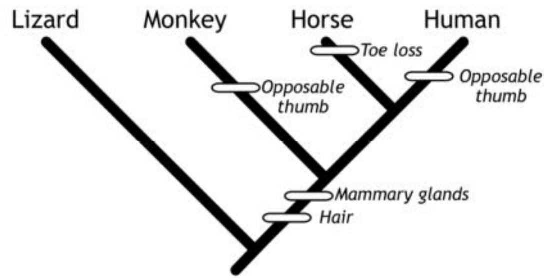


In addition to illustrating the evolutionary history of these four groups, the above cladogram also indicates the evolutionary transitions that produced the shared, derived traits.

In interpreting such cladograms, what is important is the pattern of branching, that is the specific **clades** (natural evolutionary groups) that are produced. Any **node** (point at which lineages diverge; this represents the most recent common ancestor) can be rotated, and the entire cladogram can be rotated. However, each of the clades ([human+monkey], [human+monkey+horse]) are the same. For example, all of the following cladograms represent the same exact evolutionary hypothesis:



These cladograms represents a *hypothesis* about the evolutionary relationships of these four taxa, but of course it is not the only possible relationship. Fourteen other combinations of relationships are possible among just these four species. How then do we choose which is best (most likely to be correct). Why is this one better than any of the others? The best approach is to examine each of the possible cladograms by mapping the evolutionary transitions onto them. Consider the following alternative hypothesis, in which horses and humans form a clade (centaurs?):



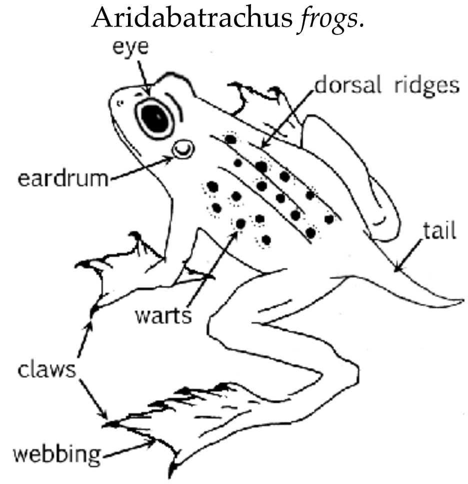
In order to account for distribution of traits among these taxa, the opposable thumb must have either evolved twice independently (as illustrated), or evolved in the common ancestor of monkeys, humans and horses, but was subsequently lost in horses. This phylogenetic hypothesis requires more evolutionary transitions than the first cladogram, and thus is considered less likely to be correct (though not impossible). In other words, the cladogram that requires the fewest evolutionary transitions to account for all of the characters is considered to be the most **parsimonious** and is the preferred hypothesis. Evaluating alternative cladograms is almost always done by computer, since the number of possible cladograms increases rapidly as more species are included (for example, adding just one more species to our analysis increases the number of possible cladograms to 105).

In the following examples and problems, we will use a data set of character states to derive a phylogeny for several hypothetical species. In order to simplify the process and make it possible to solve without computer analysis, we can assume that all traits are homologous with no convergent evolution. Thus, our primary goal will be to determine which character states are ancestral and which are derived.

Exercise 2: Cladistic Analysis of Frogs.

1. We will work as a class on the following hypothetical problem. Be sure to fill in the table and phylogeny.
2. The first step is to examine the species and present a character matrix. The illustration at right is a composite frog identifying all of the relevant traits. The species are illustrated on the following page. Record the character states of each of the frog by filling out the table that follows. In most cases (except where indicated otherwise in the footnotes), simply indicate if the trait is present or absent.
3. Once you have completed the table, identify which state is ancestral versus derived for each

Fig. 2. *Key to the characteristics of* Aridabatrachus *frogs.*



character. This will require comparisons to the outgroup. In this example, *Verdibatrachus maricopa* is the outgroup and is used to identify the ancestral states. You may find it helpful to **highlight the derived** states in the table below.

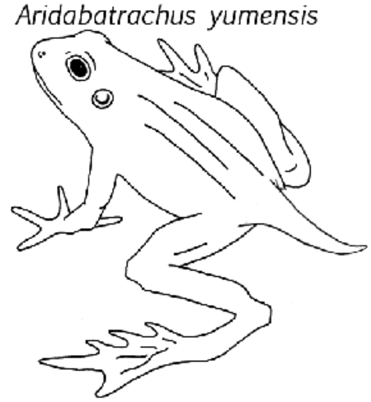
Verdibatrachus maricopa

Aridabatrachus gilensis

Aridabatrachus pinalis

Aridabatrachus pima

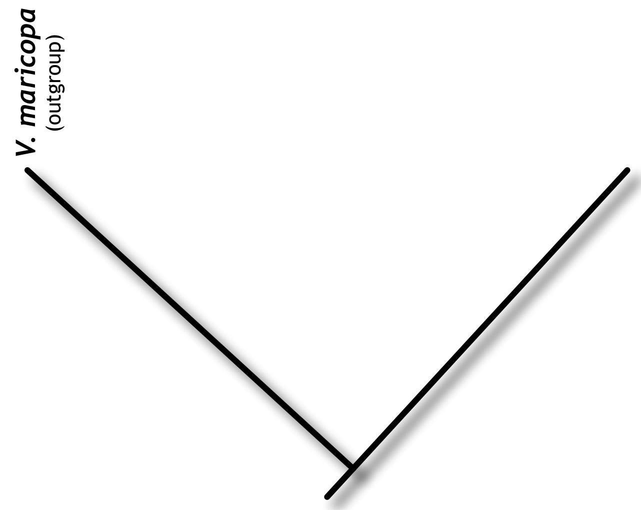
Aridabatrachus yumensis



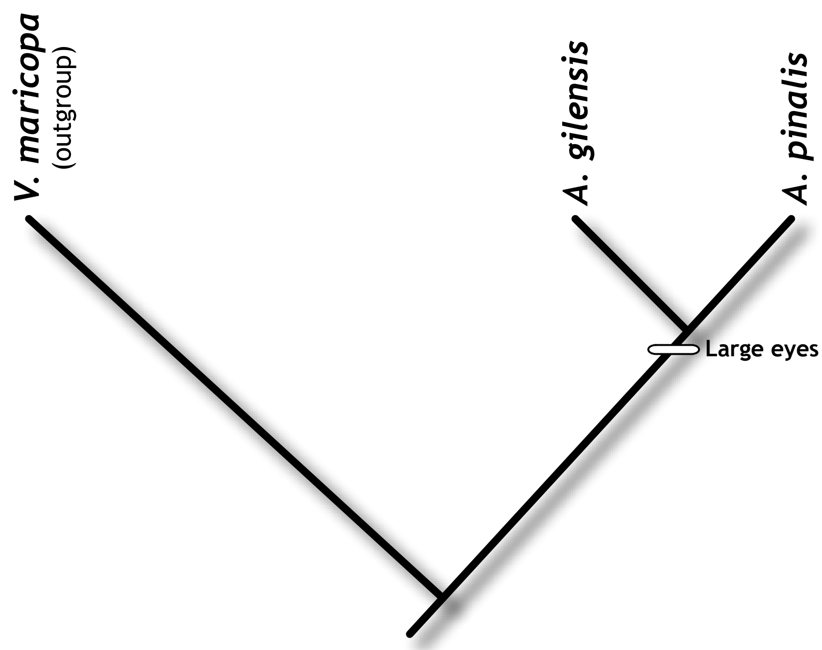
Aridabatrachus chochisus

Character	*V maricopa* (outgroup)	*A. gilensis*	*A. pinalis*	*A. pima*	*A. yumensis*	*A. cochisus*
Eyes						
Eardrum						
Claws						
Warts						
Dorsal ridges						
Webbed toes						
Tail						

4. Now you will begin to produce the actual cladogram (phylogenetic tree) for these frogs. Start by drawing a shallow V. The left branch of the V will represent the outgroup (it is common practice to place more primitive species on the left side and more derived species to the right, but it is not absolutely necessary). The right branch will represent one of the other species.



5. Next, identify a **derived trait** that is **shared by only two species**. Such a trait indicates that those two species are each other's closest relatives and should descend from a recent common ancestor (share a single node on the tree). For example, only *A. gilensis* and *A. pinalis* have large eyes. Add these species to the right side of the cladogram as shown below:



6. Include the derived homologous traits that unite this clade with labeled crossbars. They are placed on the lineage just before the node representing the most recent common ancestor since those traits must have appeared before the point of divergence. Note that only the transition to the derived state is included. The evolution of the ancestral state would fall outside of this phylogenetic tree.

7. Continue by looking for any other pairs of species that share a unique synapomorphy. These too will form a sister group, but it may not be immediately certain where they will fit relative to all of the other clades. Look for species that shares traits with *A. gilensis* and *A. pinalis*. This species or group can be added as a sister group to the *A. gilensis* and *A. pinalis* clade. Continue to add species, but note that the cladogram may not have a purely ladder-like structure. By definition, no branches should be drawn off of the left (outgroup) branch. Mark all evolutionary transitions on your cladogram.

Exercise 3: Cladistic Analysis of Gastropod Shells.

1. In this exercise you will proceed as we did above, but you will work in pairs to determine the phylogenetic relationships of the sea shells that are at your table.

2. To help locate the characters involved, you will need to know some terminology, illustrated at right (Fig. 3).

3. The identification of the five species in lab are shown below (Fig. 4). The moon shell is the outgroup.

Fig. 3. *Structural features of gastropod shells.*

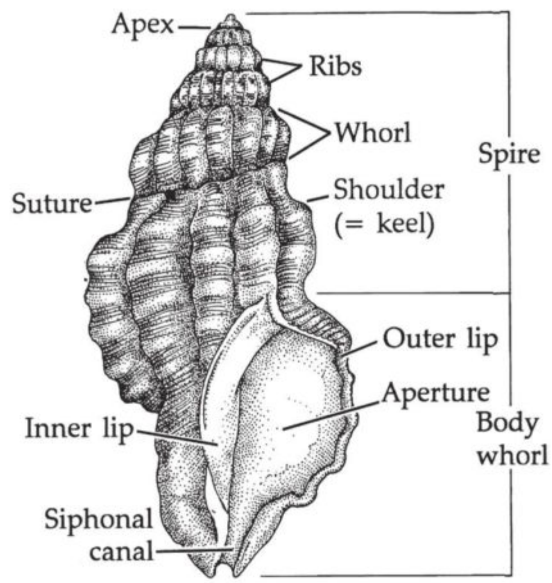
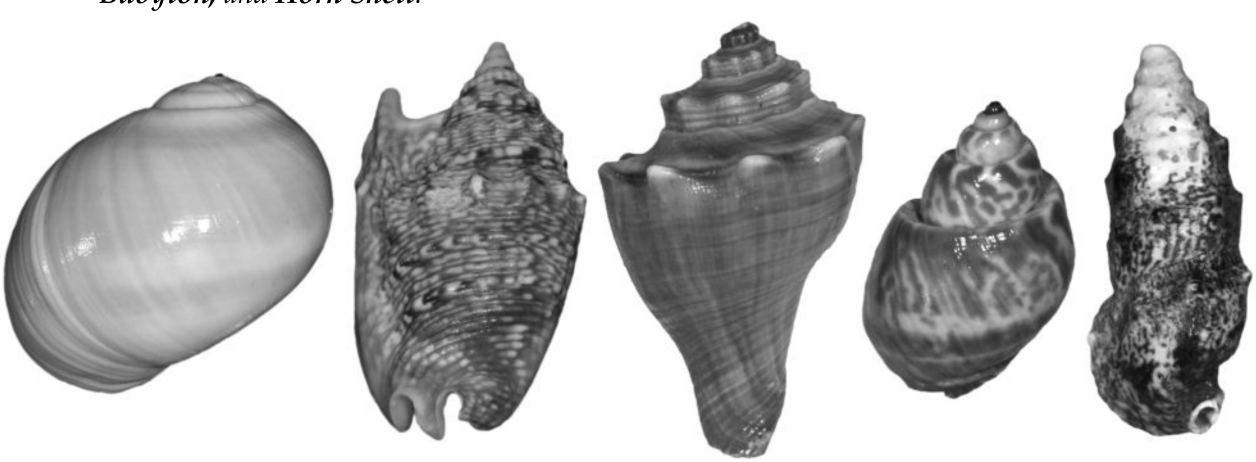


Fig. 4. *The five species in lab are, from left to right:* ***Moon shell; Strombus****;* ***Fighting Conch****;* ***Spiral Babylon;*** *and* ***Horn Shell****.*



4. For each species of shell, note the following characteristics to use in your analysis. Record the results in the character matrix on your worksheet.
   - Outer lip: thin or thickened (relative to shell thickness)
   - Shell: smooth or with *horizontal* grooves
   - Protruding bumps on shoulder: absent or present
   - Aperature shape: elongated (at least 3x the width) or oval (length < 2x width)
   - Color inside aperature: white or pinkish
   - Spire: short (barely extends above shoulder) or long and pointed
5. Use these data to derive a phylogeny for these species and record your results on the worksheet.

Exercise 4: Additional Cladistic Problems.

1. Practice applying cladistics reasoning to the additional questions on the worksheet for this lab. If there is insufficient time, you may complete these at home.

Part III — Taxonomy

Once we have some idea of an animal's relationships, we can then classify it. The traditional classification system is one developed in the 1700s by Linneaus. This system places organisms into nested groups, which each group being assigned a specific level, or rank, in the hierarchy. The major ranks, in descending order of size and generality, are Kingdom, Phylum, Class, Order, Family, Genus, and Species.

Under such a system, the dinosaur *Tyrannosaurus rex* would be classified as:

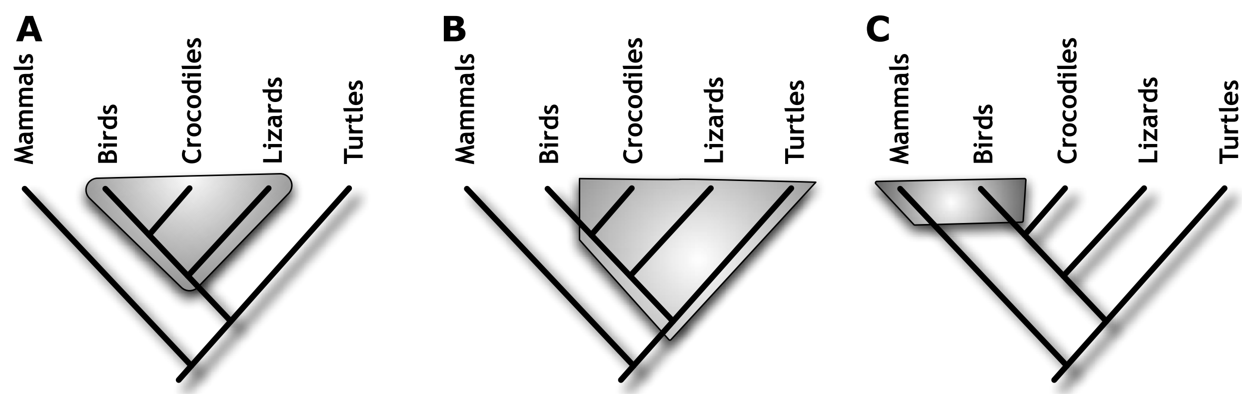
- Kingdom Animalia
  - Phylum Chordata (vertebrates and some close relatives)
    - Class Reptilia (reptiles)
      - Order Theropoda (the predatory dinosaurs)
        - Family Tyrannosauridae
          - Genus *Tyrannosaurus*
            - Species *rex*

Note that the last two categories, **genus** (plural genera) and **species** (same for both plural and singular) make up a species' **scientific name**, or **binomial**. The scientific name is always *italicized* (or underlined if handwritten) and only the genus name is capitalized, as such: *Tyrannosaurus rex*. Because differences between species are often too subtle to be recognizable from a few fossils, it is common to talk about dinosaurs just using their genus name.

This system is falling out of favor by modern paleontologists, however, because it is rather limited in its ability to accurately reflect evolutionary relationships. For example, the traditional classes Reptilia (reptiles) and Aves (birds) obscure the fact that birds evolved from within the reptile group and that some reptiles are more closely related to birds than to other reptiles.

Modern phylogenetic classification (which is controversial) names specific branches on a phylogenetic tree, but does not assign those names to any ranks (such as phylum or order). It also makes sure to name only **monophyletic** groups. A group is monophyletic if every member shares a common ancestor and if all of the descendents of that common ancestor are included in the group (Fig. 5A). In contrast, a **polyphyletic** group is one in which the common ancestor of the members of the group would not be included (Fig. 5C). This usually happens when organisms are grouped together based on convergent characteristics. A **paraphyletic** group is one in which the common ancestor is included, but the group omits some of the descendants of that common ancestor. For example, reptiles is paraphyletic because the common ancestor of turtles, crocodiles, lizards and snakes would also be considered a reptile, one group that descended from that same ancestor, the birds, is excluded (Fig. 5B).

Fig. 5. *The shaded areas indicate the types of taxonomic groups. A = monophyletic; B = paraphyletic; C = polyphyletic.*



Exercise 5: Types of Taxonomic Groups Problem.

1. Identify the monophyletic, paraphyletic, and polyphyletic groups in the phylogeny on the worksheet for this lab.

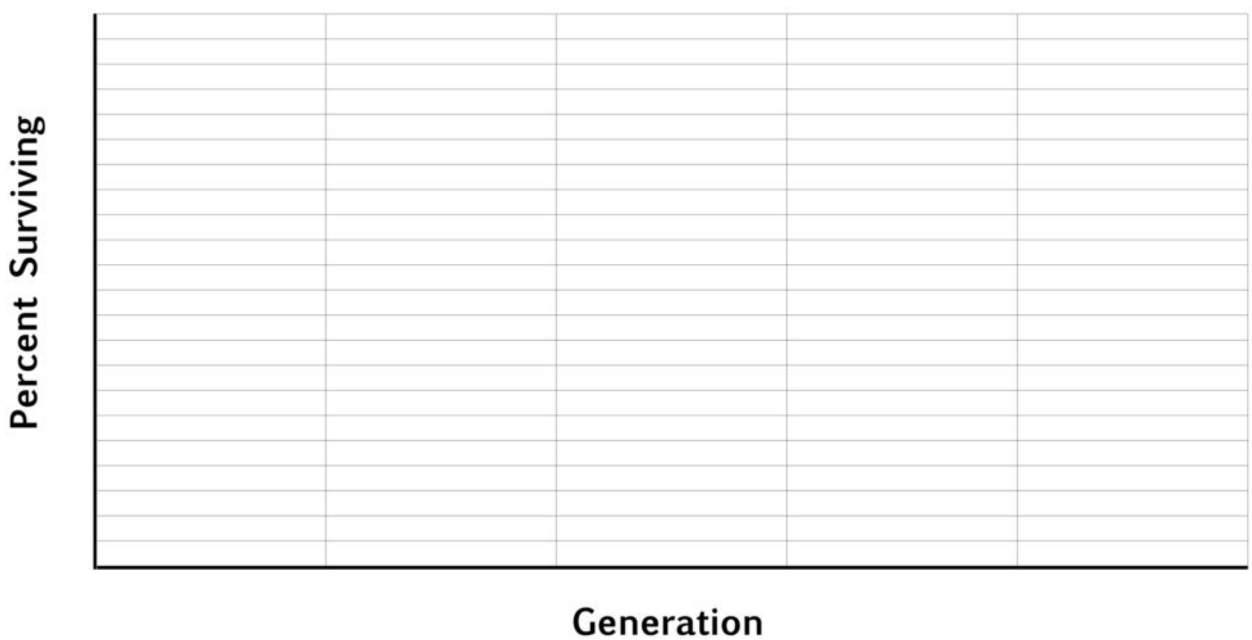
Lab 4 Evolution & Phylogenetic Analysis Worksheet

Part 1. Natural Selection Simulation.

1. Fill in the following table with the results from your Natural Selection simulation, indicating the number of each color that survived and reproduced.

	Generation							
	0 (start)		1		2		3	
Prey Color	No.	%	No.	%	No.	%	No.	%
	10							
	10							
	10							
	10							
	10							

2. Graph the results of the selection experiment below, using a line graph. Use colored pencils to represent each of the prey colors. Don't forget to add the appropriate numbers to the axes.



3. Which color prey declined in abundance? If more than one, which color declined most rapidly?

4. Were any prey colors lost from your population? If not, how many generations of predation would you estimate it would take before one of the color variants was lost?

5. Which prey colors increased in abundance?

6. Is the decline or increase of certain colors related to the common colors present in your fabric? If so, explain your results.

7. How might the results be different if you carried out these experiments using a solid-color background (such as solid green) instead of the patterned fabric?

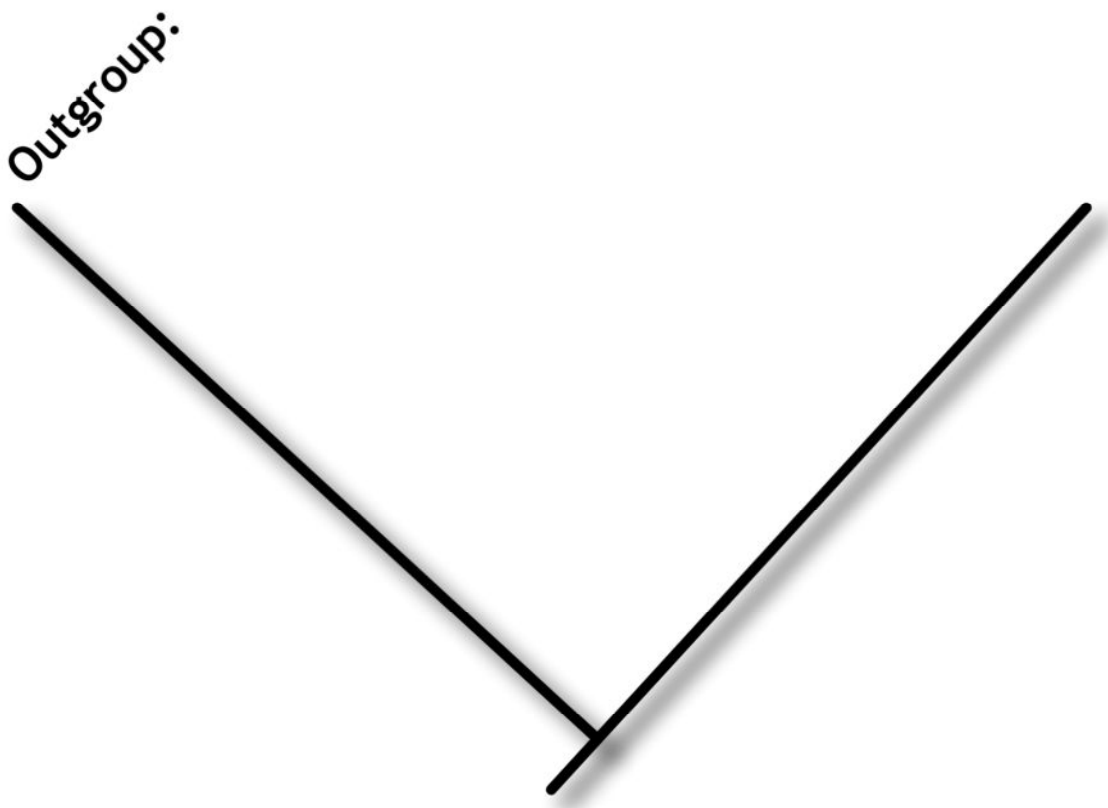
8. Imagine a new mutation that produced an individual with a purple color. Do you think this trait would spread successfully in your population? Explain why or why not?

Part 2. Gastropod Shells.

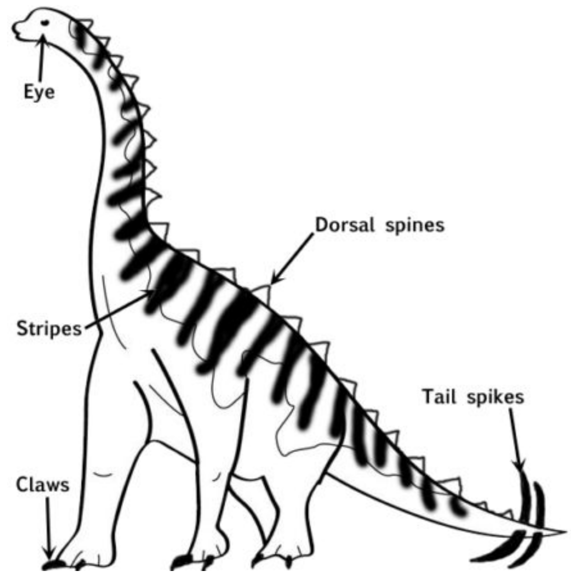
9. Fill in the following character matrix for the gastropod shells that you observed in lab.

Character	Moon shell (outgroup)	Strombus	Fighting conch	Spiral Babylon	Horn shell
Outer lip thickness					
Shell texture					
Shoulder bumps					
Aperature shape					
Aperature color					
Spire					

10. Complete the following cladogram for the sea shell species included in the above matrix. In addition to adding the species, *you should also indicate all of the evolutionary transitions to the derived states* (as was done for the fish cladogram in class).



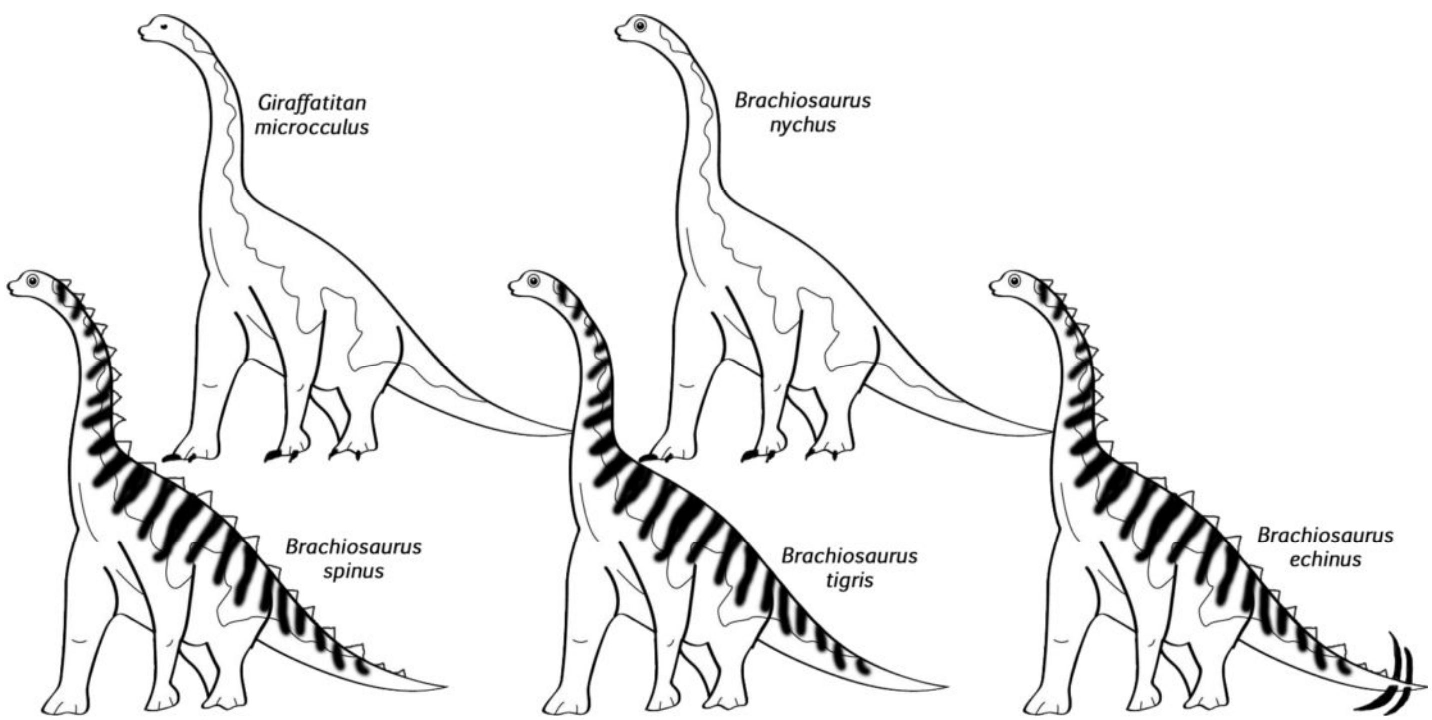
Part 3. Sauropod Dinosaurs.



Imagine that you time travelled back to the Jurassic Period and you have discovered several new species of sauropod dinosaurs in the genus *Brachiosaurus*, based on characteristics that were not preserved in the fossil record. Determine their phylogenetic relationships based on the following characteristics:

- Eyes are large or small
- Dorsal spines present or absent
- Claws present or absent
- Stripes present or absent
- Tail spikes present or absent

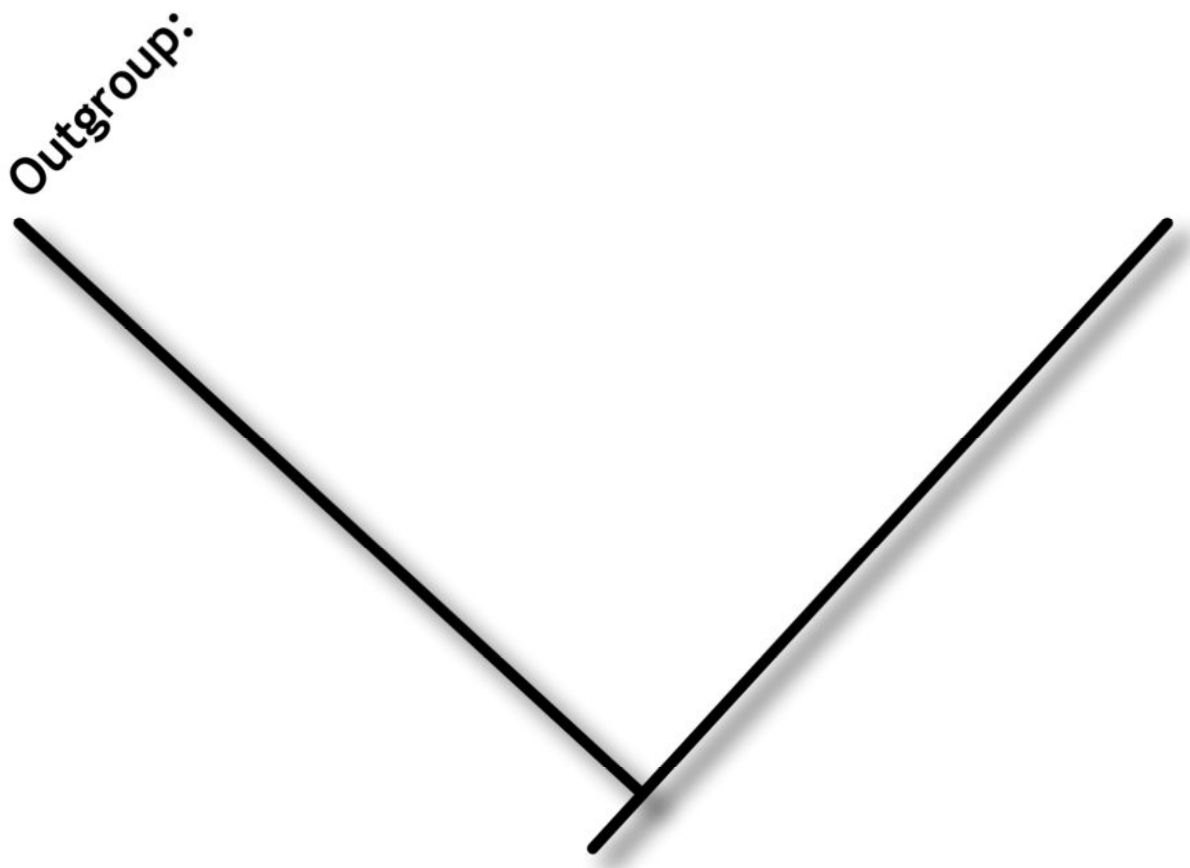
The four species of *Brachiosaurus*, plus an outgroup, *Giraffatitan microcculus*, are as follows:



11. Fill in the following character matrix for these dinosaurs, including the outgroup, *Giraffatitan microcculus*. Fill in all cells: do not leave blanks.

Character	*Giraffatitan microcculus* (outgroup)	*Brachiosaurus nychus*	*Brachiosaurus spinus*	*Brachiosaurus tigris*	*Brachiosaurus echinus*
Eye size					
Dorsal spines					
Claws					
Stripes					
Tail spike					

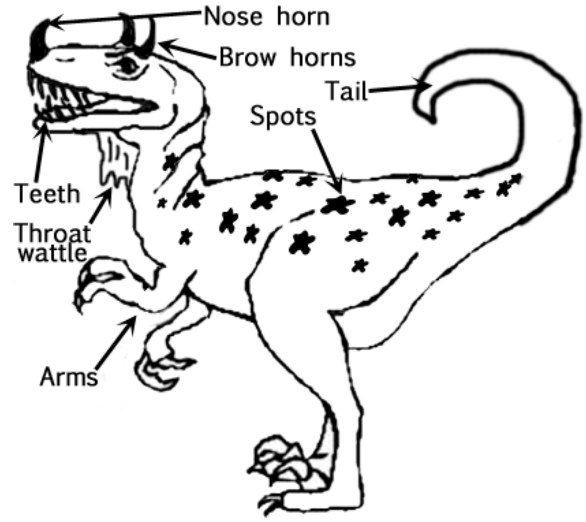
12. Complete the following cladogram for the *Brachiosaurus* species included in the above matrix. In addition to adding the species, you should also indicate all of the evolutionary transitions to the derived states.



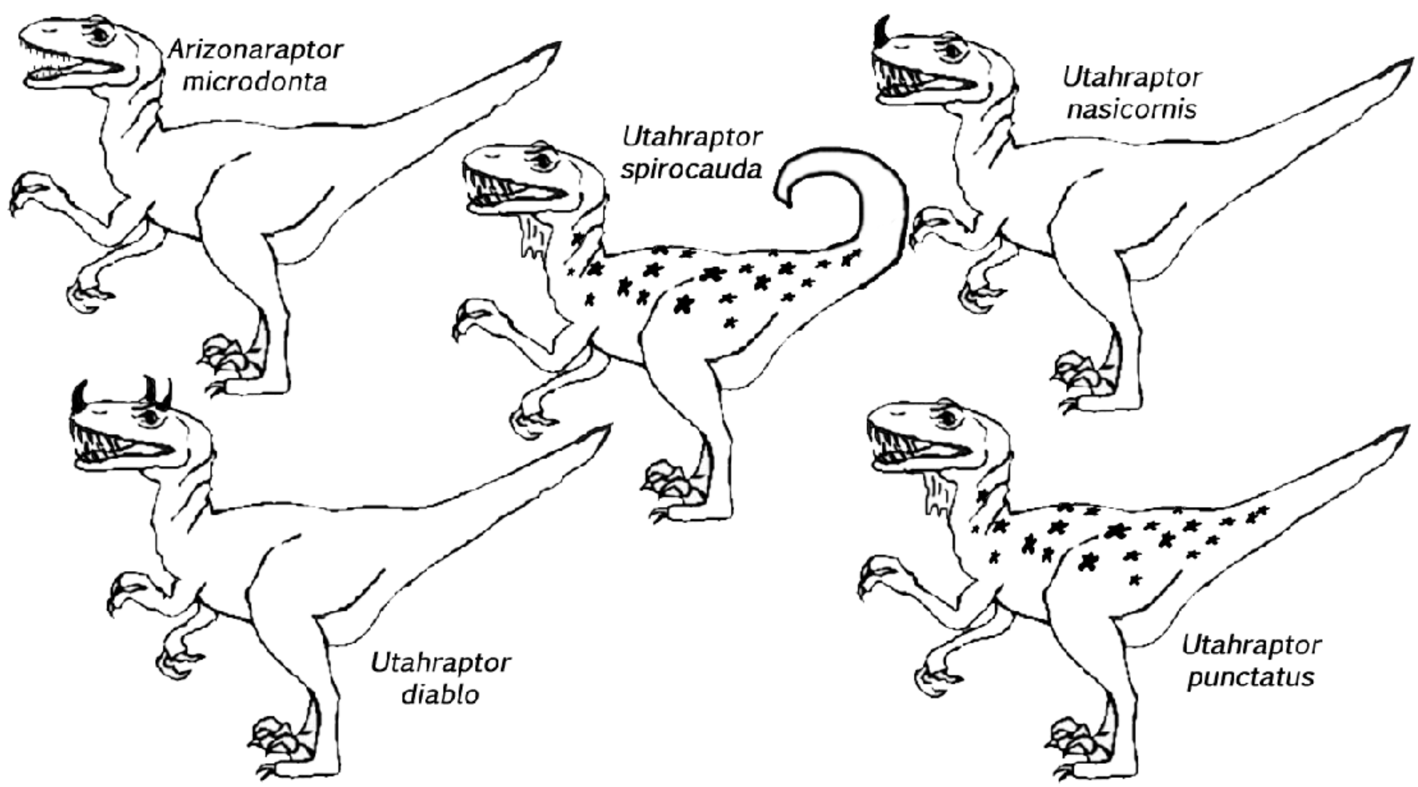
Part 4. Utahraptor Dinosaurs.

In addition to your trip to the Jurassic, you also made a stop in the Cretaceous and observed some *Utahraptors*. Determine their phylogenetic relationships based on the following characteristics:

- Teeth are long (shown) or short
- Nose horn present or absent
- Brow horns present or absent
- Throat wattle present or absent
- Arms long or short (shown)
- Spots present or absent
- Tail curled (shown) or straight



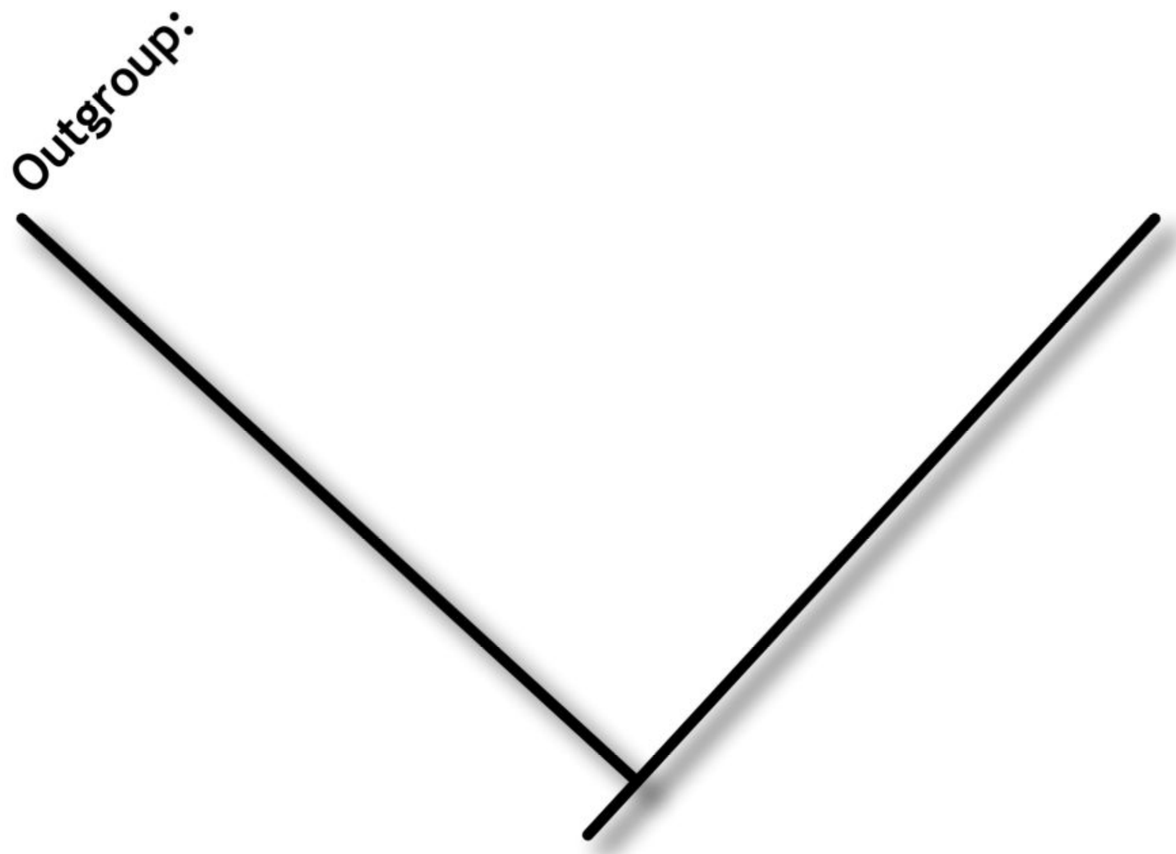
The four species of *Utharaptor*, plus an outgroup, *Arizonaraptor*, are as follows:



13. Fill in the following character matrix for these dinosaurs, including the outgroup, *Arizonasaurus microdonta*. Fill in all cells: do not leave blanks.

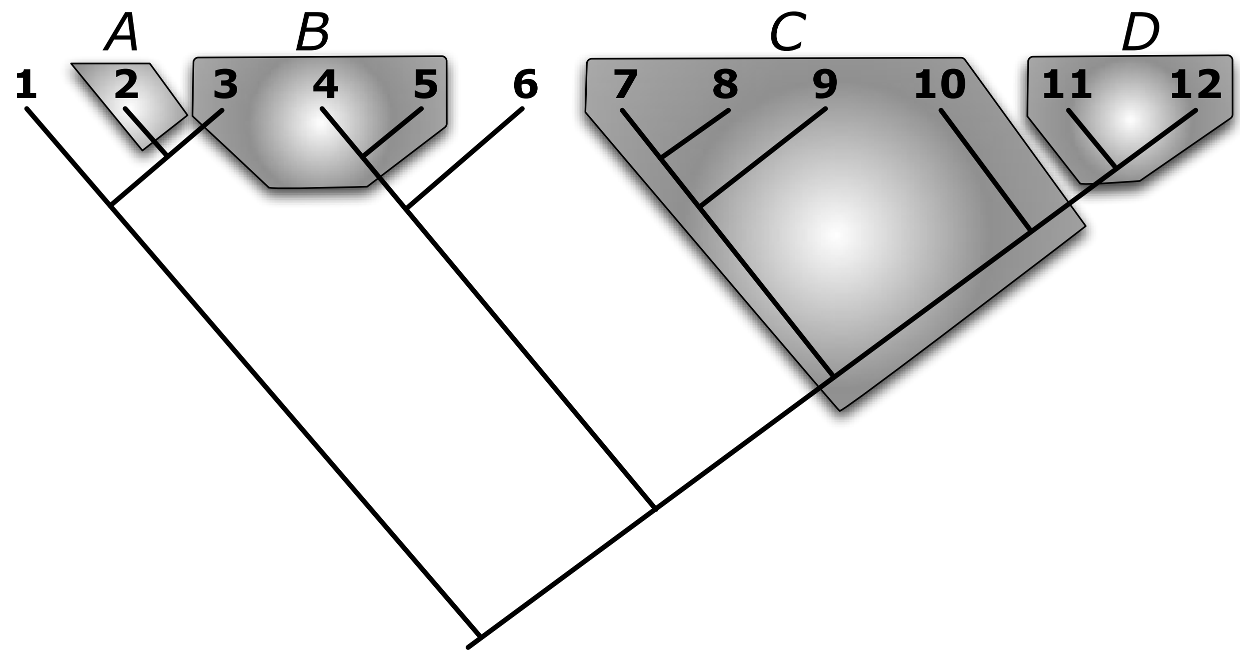
Character	*Arizonasaurus microdonta* (outgroup)	*Utahraptor spirocauda*	*Utahraptor nasicornis*	*Utahraptor diablo*	*Utahraptor punctatus*
Tooth length					
Nose horn					
Brow horns					
Throat wattle					
Arm length					
Spots					
Tail shape					

14. Complete the following cladogram for the *Utahraptor* species included in the above matrix. Also indicate all of the evolutionary transitions to the derived states.



Part 5. Classification.

15. For the following phylogeny of 12 species (numbered 1-12), indicate on the blanks below if the shaded groups (indicated by the letters A-D) are monophyletic, paraphyletic, or polyphyletic.



A: ______________________________

B: ______________________________

C: ______________________________

D: ______________________________

FIELD TRIP INFORMATION

When?

This field trip is a required part of this class and will be held on Saturday, September 24th. It is in lieu of a regular lab which will not be held that week.

Where?

We will be traveling to an area northeast of Payson, AZ, where we will look for marine invertebrate fossils at one or more sites. These sites are of the Naco Formation, Pennsylvanian Period, and were deposited about 310 million years ago. At that time, this area was covered by shallow tropical seas. We hope to find brachiopods, bryozoans, and crinoids (Echinodermata). The elevation is approximately 1700 m (5600 ft).

Traveling Information

- We will minimize the number of vehicles, ideally no more than 3
- We will meet at 8:00 am in Parking Lot 7 behind the CLCC building.
- The one-way distance is about 115 miles (roughly 2.3 hours driving time).
- Expect to return to campus around 4:00 pm (but delays are possible)

Assignment

We will collect fossils in a systematic fashion that will be elaborated on in the field. You need to make sure to collect all of the fossils from your assigned plots and place them in a labelled container. The fossils we collect will be identified and counted in next week's lab. We will use these collected fossils to ask questions on the abundance and distribution of various fossil species that we find and collect. Furthermore, we will make measurements of selected types to investigate allometric changes in shape in relation to body size. An additional guide and worksheet will be posted at a later date to cover the in-class work.

Directions

We will all meet at ASU and try to remain together as we travel to the site. However, if anyone does get separated, I have included the directions here.

Make your way to Hwy 87 (Beeline Hwy) in Scottsdale or Mesa and take this road north all the way to Payson. In the town of Payson, turn right at Hwy 260 (east), and note your odometer reading. Continue east for around 14.8 mi and look for a small green sign on the right that says simply "Paleo Site." The highway should be divided at this point unless construction is forcing the use of only one side. Turn right here into a fairly large parking area below highway level. If you reach the turnoff for Kohl's Ranch you have gone about 1 mile too far.

We may also visit an additional site in the nearby National Forest, possibly as an optional extension for anyone interested. This will involve travel on well-maintained dirt roads that should pose no difficulty for passenger cars.

What to bring

Required:

_____ Water: *at least* 2 quarts (there is none available at the fossil sites)
_____ Sturdy closed-toed walking or hiking shoes
_____ Sunscreen and/or longsleeved shirts and hats (UV intensity is greater at this elevation)
_____ Notebook (any size, but small ones are more convenient; we will provide clipboards)
_____ Pens or pencils
_____ Fossil identification guide

Recommended:

_____ Leather or work gloves
_____ Small container or ziplock bag for holding fossils that you collect for yourself, outside of the sampling area
_____ Sunglasses or other eye protection (we will also provide safety goggles)

Optional (we will provide some magnifiers and tools as well):

_____ Hand magnifying lens
_____ Geologist's or similar pick, small garden trowel, or small crowbar
_____ Camera

Lab 6 — Analysis of Diversity and Variation in a Fossil Community

Introduction.

Last weekend we travelled to a site that exposed a shale-limestone bed of the Naco Formation. This formation is dominated by marine invertebrate fossils, including brachiopods, molluscs, and echinoderms. All three of these groups are bottom dwelling, more or less sessile (i.e. attached to rocks or the bottom) and are filter feeders, straining small food particles from the water. Although free-swimming animals that feed on larger prey no doubt existed in this environment, they are rare as fossils, perhaps due to their mobility or lack of hard shells.

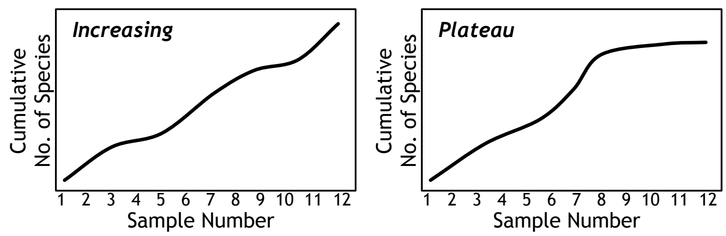
We collected fossils from two different locations and today we will identify the fossils and analyze the results. The first step is to identify what you collected. Use the Fossil Guide Handout to help identify the fossils you obtained. Do not hesitate to ask for assistance if you are having trouble identifying something.

Exercise 1: Fossil Identification.

1. Sort through your fossils and identify each type you collected. It may help to place them in piles of the same type.
2. Count the number of individuals of each species that you had in your collection (do not count any fossils you collected for yourself outside the defined sampling area). Also include broken or fragmentary fossils.
3. Record the results in **Table 1** at the end of this handout, and then record the results on the board (or class computer). Be sure to specify the identify of any fossils not listed on the table and confirm the identification with your instructor.
4. Once all students have recorded their data, record the class data on **Table 2** at the end of the handout. Each person's set of specimens is a single "sample."
5. Add up the number of specimens for each species across all samples in the column at right. Add up the number of **individual fossils** and number of **species** collected in each sample. Determine the **cumulative number of species** (combined number of species in that *and all previous samples*) for each sample as you read from left to right. (For example, if sample 1 had species A, B, and C, and sample 2 had species B and D, the cumulative number of species after sample 2 would be 4)
6. You will use these data to analyze species diversity and community differences as described below.
7. Present your findings as a short (3-4 page) report in the format of a scientific paper. Your paper should have a brief introduction, methods, results, and discussion section. Details on the organization of a scientific paper is available as a separate handout on the course web page.

Analysis 1 — Species Sampling Curves

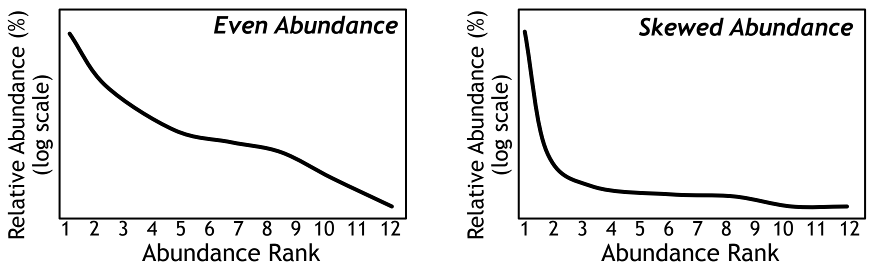
One of the first questions we can ask about our community is how well we have sampled it. Do our samples represent a relatively complete sample (sampling biases not withstanding) or might we expect to find many additional species with more sampling effort. One simple way to address this question is by drawing a **species-area** or **species-sample curve**. In such a graph, the cumulative number of species produced with the addition of each sample is plotted against sample number. The shape of the curve provides and indication of the completeness of the sample. As more and more samples are added, there should be fewer and fewer new species as the area becomes more throroughly sampled. If the graph still has an upward slope (as shown below left), this suggests that the maximum number of species has not been reached. If, on the other hand, the curve has reached and maintained a plateau (below right), then it is likely that the habitat or geological formation has been adequately sampled for all but very rare species and that many new species are unlikely to be added.



For your analysis you should graph the species-sample curve using the class data from both areas. You may neatly hand draw the graph but it is perferable to make your graphs using *Excel* or other graphing software (there are numerous online tutorials to help you with the graphing functions in *Excel*, which vary with version). The discussion of your paper should use these graphs to determine if the site was well-sampled.

Analysis 2 — Species Diversity in an Ancient Community

As you peruse the class data on the abundance of different species of invertebrates, you may notice that some species are much more common than others. This is a common observation in modern communities as well. One way to describe this pattern is with a graph that plots the relative rank of abundance, from most to least abundant, against the relative abundance (as a percentage of the total) for each species, plotted on a log scale. If the graph forms a relatively straight line that decreases evenly (as shown below left), this indicates that the relative abundance of species is fairly even. In other words, the common species is not that much more common than the least common species. On the other hand, if the curve is skewed, so that it appears hollowed or concave (dropping steeply at first and then levelling off; see below right), then that indicates that one or a few species are much more abundant than the others, while most of the rest are relatively rare. Such a community will appear to be less diverse than a community with the same total number of species but with a more even number of each. In modern communities, highly skewed distributions are often associated with disturbed areas.



The first step is to organize the data. Use the totals across all samples (right hand column of Table 2). Sort the species from most to least abundant (total number of individuals), and then assign each species a rank, from 1 for the most abundant, 2 to the second-most abundant, and so on and record in Table 3. Calculate the relative abundance by dividing the number of individuals by the total number of individual fossils of all species combined. Multiply by 100 to convert to a percentage.

To plot the rank-abundance curves, you will need to tell *Excel* (or other graphing software) to use a **log scale** on the vertical (Y) axis (do *not* plot the horizontal (X) axis on a log scale). Since the exact method of producing a log scale on the axis varies among versions of *Excel*, you should check appropriate online tutorials for your version if you need help. Alternatively, if you are unable to get the log scale to work, or if you are hand drawing the graphs, you can instead take the $\log_{10}$ of each of the relative abundance data and then plot these data on a linear scale.

In the discussion of the paper, visually evaluate these graphs to determine if the rank-abundance relationship reflects a relative even or a skewed abundance.

Analysis 3 — Sampling Comparisons

When we sampled the fossils, we collected from two different types: directly from the uneroded cliff side, and from the loose material that had previously eroded out. This allows us an opportunity to study the way that erosion may alter the fossil record and change how we perceive prehistoric communities. We will examine two measures of these communities: species richness (the number of species) and the number of individuals observed.

Descriptive Statistics

In order to compare communities, we must first describe them statistically. We will need to describe both the central tendency of a set of data, that is, what is a typical value for that sample, and its variablity. The two most common measures of central tendency are the **mean** (numerical average) and **median**, which is the middle value when the values are ranked from lowest to highest. For example, for the following values: 1, 2, 2, 4, 6:

The **mean** (usually written $\overline{X}$) equals (1+2+2+4+6)/5 = 3
The **median** equals 2

The nature of the particular data determine whether the mean or median is the preferred measurement for analysis, but this is beyond the scope of this class.

We use several different measures to describe the variability of a sample. The simplest is the **range**, from the lowest to highest value. This measurement is very sensitive to sample size, so is of limited use. More commonly, either the **standard deviation** or the **standard error** are used to describe the variability of a data set. The standard deviation equation is as follows:

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{N - 1}}$$

where s is the standard deviation, x is the value of each sample, $\bar{x}$ is the mean of all of the samples, N is the sample size (number of samples) and Σ is the summation sign. Using the numbers from the above example, the standard deviation would be calculated as:

$$s = \sqrt{\frac{(1-3)^2 + (2-3)^2 + (2-3)^2 + (4-3)^2 + (6-3)^2}{5-1}} = \pm 2$$

With larger samples, calculating standard deviation by hand can be tedious, but can be calculated in *MS Excel* quite easily using the formula "**=Stdev(array)**" where "array" is the list of numbers or cell addresses that you want to calculate the standard deviation of. One standard deviation above and below the mean encompasses about 65% of the data, while two standard deviations encompass about 96% of the data.

The standard error is closely related to the standard deviation, and is calculated by the formula:

$$SE = {}^{s}\!/\!_{\sqrt{N}}$$

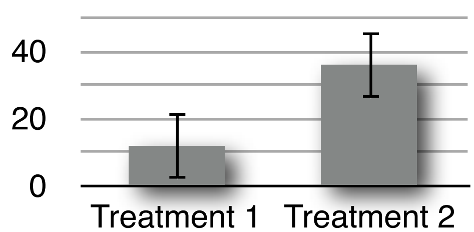
Although the standard deviation is more widely used, the standard error has the advantage of being useful for a quick-and-dirty statistical test (see below).

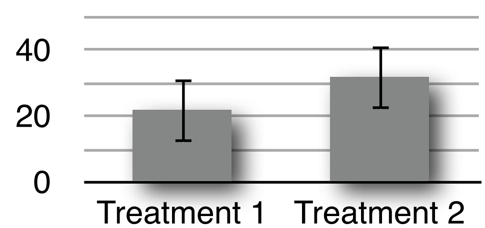
Inferential Statistics

Beyond simply describing data, we will also want to test specific hypotheses. For example, we may wish to determine if two species differ in some way. If we measure several individuals from each species and discover that their means are not exactly identical, this by itself does not allow us to determine if a difference actually exists; the observed difference may simply be due to chance given the variability in the data. Statistical tests use the variability of data (such as the standard deviation) to determine the probability that any difference or relationship observed in the data is due simply to chance.

Scientific hypothesis testing generally takes a conservative approach: it is better to conclude no effect when in actuality there is one than to conclude there is an effect when in actuality there is none. Thus, statistical tests measure the probablity (***P*-value** or simply ***P***) that any observed difference or trend is due only to random chance. Unless that probability is very low, we conclude that there is no difference. How low a probability is low enough? The (arbitrary) standard cutoff point is 0.05 or less. In other words, we conclude that there is no difference unless there is less than a 5% chance of making an error if we do conclude there is a difference.

Many different statistical tests have been developed that can be applied to a wide variety of data, but these generally require specialized statistical software and are beyond this course. Instead, we will use a "quick and dirty" approach to comparing means. This involves plotting the means of the two groups being compared and adding the standard error using error bars extending above and below the mean. The rule of thumb in this case is that if the error bars do not overlap (figure below left), then we can conclude that any difference between the means is unlikely due to random chance and that the difference is real (we say that the difference is "statistically significant"). If, on the other hand, the error bars do overlap (below right), so that the upper bar of the lower mean extends above the lower error bar of the higher mean, then we cannot conclude that there is any difference (there might be, but the data are not strong enough to be sure).





Draw bar graphs, as shown above, to compare the number of species in each of the two sampled areas. Add Standard Error bars to help determine if the difference is statistically significant. (Note: if using *Excel*, you need add the values of the calculated standard errors under the custom option or else draw them in by hand. Do **not** use the "standard error" option in *Excel*, as this will *not* give the correct result.) Draw a second graph in the same way to compare the number of individual fossils in the two areas. Discuss whether the different areas (that represent eroded vs. uneroded fossils) differ in either species number or total fossil density. What are the implications for any differences that you detected?

Table 1. Record the data from your individual sample in this table. For each species, record the number of individual fossils that you collected from the sampling plot.

Group	Species	No. Collected
Molluscs	*Myalina*	
	Bellerophon	
Brachiopods	*Composita*	
	Derbya	
	Cleiothyrdina	
	Anthracospirifer	
	Linoproductus	
	Anitiquatonia	

Group	Species	No. Collected
Bryozoans	*Fenestrella* bryozoan	
	Encrusting bryozoan	
	Branching bryozoan	
Echino-derms	Crinoid stems/disks	
	Eirmocrinus calyx parts	
Other		

Table 2. Record the *class data* in this table.

Organism	Sample Number & Initials								Totals
	Area 1: ___				Area 2: ___				
	1	2	3	4	5	6	7	8	
Myalina									
Wilingia									
Bellerophon									
Composita									
Derbya									
Cleiothyrdina									
Anthracospirifer									
Juresania									
Echinaria									
Linoproductus									
Anitiquatonia									
Fenestrella bryozoan									
Encrusting bryozoan									
Branching bryozoan									
Crinoid stems/disks									
Eirmocrinus parts									
Other:									
Other:									
Other:									
No. of **individual fossils** per sample									
No. of **species per sample**									
Cumulative no. of species									

Table 3. Use this table to organize the class abundance data (totals for all samples) and to calculate the relative abundance. If you are unable to plot these data on a logarithmic scale, you may instead plot the logs of the abundance data (right column, optional).

Rank	Total Abundance	Relative Abundance (% of total)	Log_{10} of Relative Abundance
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			

Lab 8 — Dinosaur Teeth and Diets

Introduction.

As with most other aspects of dinosaur biology, we must infer their diets indirectly using cues left in the fossil record. Even then, we can often get no more specific than "plants" or "insects" or "meat." In the broadest terms, we can categorize dinosaurs as **herbivores** if they eat primarily plants, **carnivores** if they eat mostly other animals, especially other vertebrates, **insectivores** if they eat mostly insects, and **piscivores** if they eat mostly fish. Dinosaurs with a mixed diet of both plant and animal matter are called **omnivores**.

Evidence for dinosaur diets comes in a variety of forms. One of the strongest pieces of evidence is when the actual stomach contents are fossilized and recognizable. This mostly happens when the prey has hard bones, scales, or shells that have been swallowed more or less intact, but fossil plant fragments have also been found in stomach regions of herbivores. Such fossils are rare, and it is not always clear if the stomach contents represent typical food.

Tooth marks and broken teeth left in prey animals are also valuable clues to the diets of carnivores. The larger species in particular may leave distinctive wounds in their victims' bones that can be matched by size and shape to their maker. In most cases, however, it is not be possible to determine if the carnivore actually killed the prey animal or merely scavenged it after it had died.

A third clue to diet is the fossilized feces, or coprolites, left behind. Microscopic analysis of coprolites can reveal bone or plant fragments that allow diet to be determined. The difficult part is matching the coprolite to its maker. Most often this is not possible unless its contents and size are likely to fit only one particular species known from the area. For example, some very large coprolites containing bone fragments with teeth marks have been attributed to *Tyrannosaurus*, the only large predator known from the same time and place.

The most widely available clues to an animal's diet are its bones and especially its teeth. While tooth structure would obviously be related to diet, other aspects of the skeleton can also provide clues. For example, chewing requires complex musculature and proper alignment of teeth that is reflected in the position of the jaw joint and areas of muscle attachment. Digesting vegetable matter is a slow process and requires a large gut to house the plant matter being digested. The shape of the ribs and pelvis can indicate a large gut and implies an herbivorous diet. On the other hand, large sharp claws might indicate the need to attack other large animals and thus a carnivorous diet.

In today's lab we will start by examining the teeth of modern animals to discover how tooth structure relates to diet and feeding mode. You will then have an opportunity to examine actual and replica dinosaur teeth to determine their likely diet.

Herbivore Food.

Although it may seem sufficient to simply consider "plants" as the diets of herbivores, we often want to know more than that. The types of plants an herbivore fed on is related to its stance and mobility and its habitat. For example, did an herbivore feed on plants that grew close to the ground or did it reach high into trees? Were the plants it fed on easily digestible and nutritious, or where they low quality? While we often cannot easily answer such questions, we can get an idea of the range of possibilities if we know the kinds of plants available in an environment. Therefore, we will begin by taking a brief survey of the major types of plants available during the Mesozoic Period.

The Mesozoic plants can be broken down into two main groups. The more primitive (and paraphyletic) group of plants reproduces using microscopic spores and, during the Mesozoic, consisted mostly of relatively low-growing herbaceous or shrub-like plants. These include the lycopods (club mosses), horsetails, and ferns. A more derived group of plants reproduce using seeds. These are the cycads, ginkgoes, gnetophytes, conifers, bennettites, and flowering plants (angiosperms). All but the seed ferns and bennettites have surviving members, and these are briefly described below:

Lycopods (club mosses) — related to ferns and horsetails, these plants are inconspicuous, low-growing creepers. While some where tree-sized during the Paleozoic Era, those from the Mesozoic onward were small and low-growing.

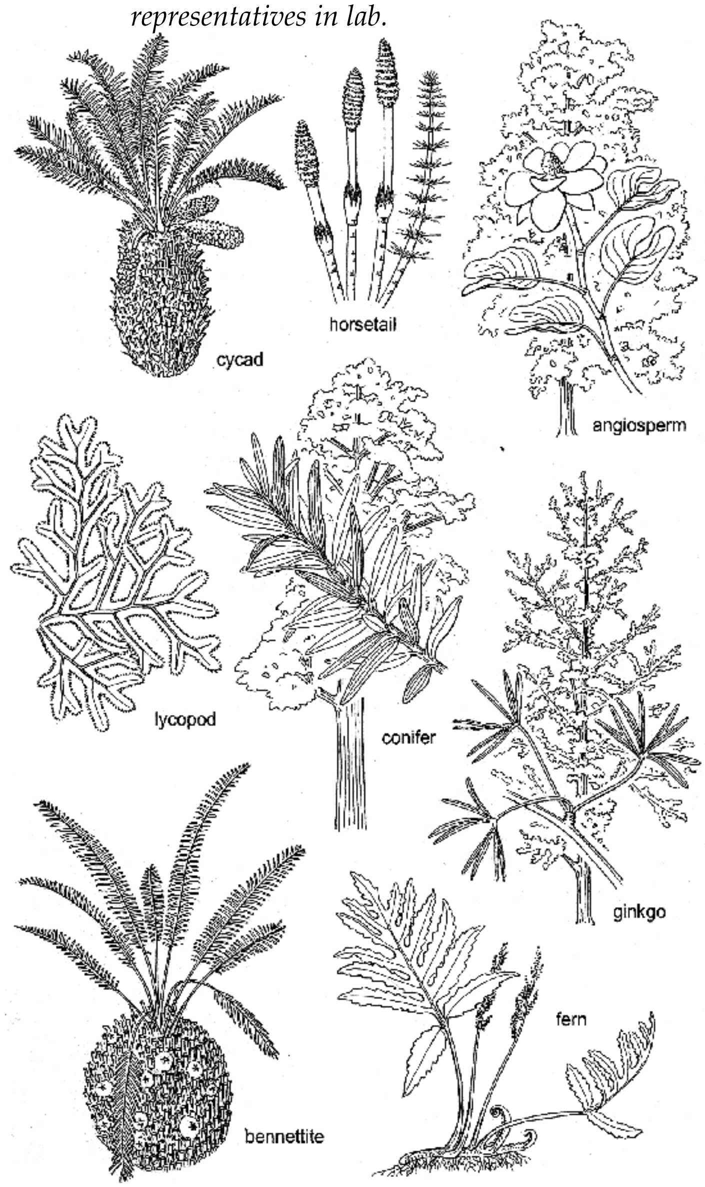
Horsetails — As with the club mosses, they were dominant tree-like plants during the Paleozoic, but were supplanted by the seed plants. The Mesozoic and modern forms were very similar, forming slender reed-like stalks.

True ferns — A familiar group of plants that are mostly low-growing herbaceous plants, although some are tree-sized. Although ferns extend back to the Paleozoic Era, they underwent considerable diversification during the Cretaceous Period and may have been the most common browse for low-feeding dinosaurs.

Seed ferns — Although their leaves resemble those of ferns, they are actually a type of seed plant, perhaps most closely related to cycads. They declined during the Mesozoic Period and are now extinct.

Cycads — Cone-bearing seed plants with stout trunks and superficially palm-like leaves. Only a few species persist today, but during the Jurassic Period they were very common and diverse.

Figure 1. *Major types of Mesozoic plants. All but the bennettites have living and/or fossil representatives in lab.*



Gnetophytes — Gnetophytes are known from the Permian Period on, and were fairly common during the Cretaceous Period. They may be related to the extinct Bennettites and to flowering plants. The few (about 70) surviving forms, such as *Ephydra* and *Welwitschia*, are very unusual plants of deserts and tropics.

Ginkgoes — Trees with fruit-like seeds and distinctively shaped leaves. There is only one surviving species (native to China), but they were quite diverse throughout much of the Mesozoic Era.

Conifers — These are the familiar pine, juniper, and firs trees that produce seeds in cones. Very common and diverse, they were the dominant plants during the Triassic and Jurassic, but declined in the Cretaceous following the diversification of the flowering plants.

Flowering Plants (Angiosperms) — The last group of plants to evolve, they did not appear until the Cretaceous Period. They have flowers to attract insect (mostly) pollinators and seeds are encased in fruit to attract animal dispersers. This is the most diverse group of plants and accounts for about 90% of modern species.

Overall, during the Triassic and Jurassic Periods, forests were dominated by the conifers, cycads and, to a lesser extent, ginkgoes. Horsetails, club mosses, and especially ferns would have made up much of the lower plant growth. The dinosaurs of the Jurassic would have never encountered a flowering plant. Beginning in the Cretaceous, flowering plants came to increasingly dominate, gradually replacing most of the other plant groups (except ferns) by the end of the Cretaceous.

Exercise 1: Plant Diversity.

1. Examine the live, preserved, fossil, and model plants on display.

2. Complete questions 1-3 on the worksheet as you refer to the plants.

Diet and Skulls of Modern Animals.

Vertebrates exhibit two main ways in which they process food with their mouths. Modern reptiles and birds mostly just bite off portions of food and swallow. This requires a jaw that can produce cutting edges but does not require any grinding surfaces. Alternatively, most mammals, especially the herbivores, can chew their food. Chewing requires the presence of grinding surfaces. Animal-based food such as insects or vertebrates is easily digested and so swallowing large pieces or whole prey is not much impediment to digestion. Whether an animal chews or simply crops off some food and swallows has significant implications for the arrangement of teeth and structure of the skull

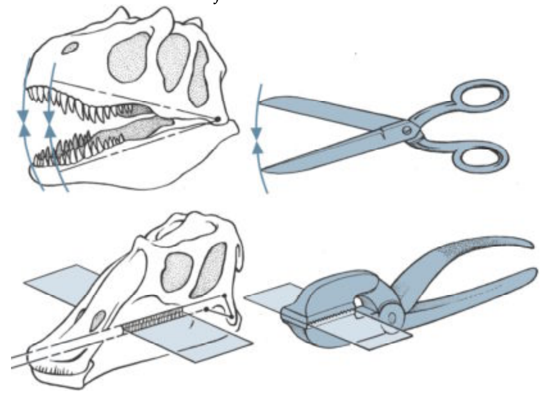
Plant material is more difficult to digest, and usually involves the assistance of bacteria in the gut. In order to improve access to plant material by bacteria, herbivores need to physically break down plant material. Herbivores that bite and swallow can improve the break-down of plant material by swallowing gravel or rocks (called **gastroliths**) to form grinding surfaces inside the stomach (or gizzard). Among modern species, this is common practice for herbivorous birds (such as chickens, geese, and ostriches) and crocodilians (which probably use the rocks more for buoyancy than digestion). Gastroliths have been found associated with a variety of herbivorous dinosaurs.

Mammalian herbivores, on the other hand, chew their food. To chew food requires not just specialized grinding teeth, but also complex jaw musculature and cheeks to keep the food from falling out. Chewing food before swallowing means that it can be accessed by digestive enzymes more rapidly than if swallowed intact, and speeds the digestive process. In mammals, the cheek teeth (premolars and molars) are the primary chewing surface.

The different requirements of cropping versus chewing also affects other parts of the skull, such as the location of the jaw articulation. In meat eaters, bites are intended to cut, much like scissors. And like scissors, the jaw hinge is in-line with the “blades” of teeth. In contrast, chewing requires the upper and lower jaws to be in contact along the entire length of grinding teeth. This is accomplished by having the jaw joint at a different level than the tooth row (Fig. 2).

While herbivores need their cheek teeth to chew, they must first bite off parts of the plant. This requires different, nipping teeth or structures at the front of the mouth. Consequently, chewing herbivores have nipping teeth or a beak at the front of the mouth, and grinding teeth along the sides. In between these sets of teeth there is a gap called a **diastema**. This pattern is easily observed in many herbivorous mammals.

Figure 2. *Cutting versus chewing action of dinosaur jaws.*



Exercise 2: Diet and Skull Structure in Mammals and Dinosaurs.

1. Study the skulls of several carnivorous mammals that are available. These include dog and coyote (*Canis* spp.), bobcat (*Lynx rufus*), Sea lion (*Zalophus californianus*) Identify the tooth rows and note that the jaw hinge is in-line with the tooth rows.
2. ***Carefully*** articulate the mandible to see its normal action. Note how the back teeth meet before the front teeth. Pay special attention to the blade-like teeth near the back of the mouth and note how they slide close by each other like the blades of scissors.
3. Now study the skulls of several herbivorous mammals, including a deer (*Odocoileus virginianus*), horse (*Equus caballus*) and a large rodent such as beaver (*Castor canadensis*). In each of these skulls, identify the nipping or cropping teeth, the **diastema**, and the grinding cheek teeth.
4. Follow the line of the cheek teeth back and note that the jaw joint is not in line with the teeth. Where practical, ***carefully*** manipulate the jaw to observe how the cheek teeth come into flat contact with each other.
5. Examine the skulls of a collared peccary (also called javelina; *Pecari tajacu*) and chimpanzee. Examine the arrangement of the teeth and the position of the jaw joint to determine their probable diets.
6. Examine the small scale skulls of several dinosaurs. Based on the characteristics of their skulls, do you think they were carnivorous or herbivorous?
7. Complete questions 4-5 on the worksheet as you refer to the skulls.

Diet, Feeding Style and Tooth Structure.

Modern animals exhibit great variation in their tooth structure. In particular, most reptiles have relatively simple teeth with a single point (**cusp**). There is little variation in the shape of the teeth within a reptile's mouth, although they may vary in size. In contrast, mammals have more complex and varied teeth with several different tooth types. Mammal cheek teeth often have complex structure with multiple cusps or ridges. Unlike reptile teeth, mammal teeth are not continuously replaced but have only two generations. Still other modern animals, such as birds and turtles, lack teeth altogether and have a horny beak instead.

Herbivorous mammals have evolved a variety of complex grinding surfaces on individual cheek teeth to produce effective grinding surfaces. The teeth of reptiles and dinosaurs are too simple to produce such complex patterns on individual teeth. Despite this, several groups of dinosaurs, notably the ornithopods (duckbills) and ceratopsians (horned dinosaurs), have evolved the ability to chew their food. Although their teeth are individually relatively simple, they produce grinding surfaces by having numerous small teeth packed together into **dental batteries**.

The following are some of the different diets of large vertebrates (this is by no means comprehensive, especially for smaller vertebrates!), and the functional characteristics of teeth and other structures associated with that diet. Tooth characteristics vary not just with diet, but also with how prey is eaten. For herbivores, plants can be cropped and swallowed or the plant material can be chewed. For carnivores, prey may be swallowed whole or chunks may be sliced off.

Hard-shelled Prey — Animals that eat hard-shelled prey (such as crabs, clams, snails, etc.) often have very thick, blunded teeth that can crush shells without the teeth breaking. Modern examples: Spotted pinfish, Sheepshead, Caiman Lizard.

Swallow Small Prey (such as fish) Whole — Fish and other aquatic prey are slippery and usually swallowed whole. Therefore, the teeth are essentially designed to grab and pierce rather than to cut. They are conical and pointed and may have a bit of curvature. Similar (but much smaller) teeth are found in insect eaters. Modern examples: American alligator, Nile crocodile, dolphin, sea lion.

Slicing Flesh of Large Prey — Animals eating flesh of other large animals (i.e., too large to swallow whole) need to shear and cut their food. Mammals with such a diet usually use the close sliding of upper and lower cutting teeth to shear food (see above), but other vertebrates rely on teeth that are laterally flattened, curved, and often with serrated edges. (Note: alligators and crocodiles do eat large prey, but do not slice prey. Instead, they grab on and twist their body to tear off chunks). Examples: dog or jackal (note cheek teeth), monitor lizard, sharks.

Plant shearing/cropping — Animals that eat plants without chewing must simply shear or cut off pieces of plant matter. Their teeth are therefore usually simple spatulate, blade shaped or spoon-shaped structures arranged in close rows that together form a serrated edge. Modern example: Iguana.

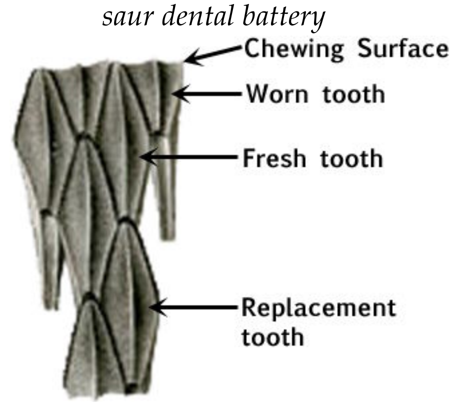
Plant chewing — Teeth must form a grinding surface, either by having multiple cusps or ridges (mammals) or having a "battery" of teeth close together which produce such a surface. Modern examples: deer, horse, beaver.

Beaks — Toothless beaks are quite versatile and can be used to cutting off plants (turtles), shearing flesh (turtles, birds), or crushing seeds (birds). It can be difficult to determine the diet of animals with beaks and no teeth. Modern examples: snapping turtle, hawk, pheasant.

Exercise 3: Grinding Surfaces and Dental Batteries.

1. Although mammals show a great deal of variation in tooth structure, the fact that they only have two tooth generation (which allows teeth to become more precisely aligned), their complex jaw musculature, and their complex multi-cusped teeth means that they are not the best models for the simpler jaws and teeth of dinosaurs. Nonetheless, they can be used to illustrate basic principles.
2. Examine the cheek teeth of the deer (*Odocoileus virginanus*), horse (*Equus caballus*) and beaver (*Castor canadensis*) or other rodent and note the various bumps and ridges that form grinding surfaces.
3. Several groups of dinosaurs have evolved the ability to chew. One of these is the hadrosaurs, or "duck-billed dinosaurs." Examine an individual tooth and note that it is relatively simple in structure: an individual tooth does not produce much chewing surface.
4. Next, examine the replica of a part of an *Edmontosaurus* jaw (a kind of hadrosaur). Look for the layers of individual teeth. Only the top layer is in use, with other teeth waiting below to replace them. The surface forms a broad grinding plate, broadly grooved in the center where it meets the other jaw (see Fig. 3). (A section of an actual hadrosaur jaw is also available, with grooves that held the teeth.)
5. Complete questions 6-8 on the worksheet as you refer to the skulls and teeth.

Figure 3. *Small section of a hadrosaur dental battery*



Exercise 4: Diet and Tooth Structure of Vertebrates.

1. Examine the teeth of an herbivorous lizard, the green iguana (*Iguana iguana*) using a dissecting scope to better see their structure. Unlike the mammals, iguanas simply crop off some vegetation and swallow: they do not chew.

1. Examine the teeth of animals that swallow their prey, such as fish, whole. Study the skulls of the sea lion, dolphin, alligator and crocodile.

2. Now examine the teeth of animals that eat hard-shelled prey, such as mollusks. We have available the jaws of two fish and the snail-eating Caiman Lizard. How do their teeth differ from those of the fish eaters?

3. Eating prey that is too large to swallow typically requires chunks of flesh to be sliced off. This is done with the narrow cheek teeth in carnivores such as dogs (note that some cheek teeth also have a flattened portion to grind and crush food). Also study the shape of the teeth in the water monitor lizard (a dissection scope may be of help).

4. The fossil teeth of three different species of mosasaurs (large sea-going lizards) are available in lab. Based on your observations of modern animals, what do these teeth suggest about the diets of these mosasaurs?

5. Examine the teeth of an herbivorous lizard, the green iguana (*Iguana iguana*) using a dissecting scope to better see their structure. Unlike the mammals, iguanas simply crop off some vegetation and swallow: they do not chew.

6. Examine the various teeth (real fossils and replicas) of dinosaurs that are on display. For each, try to determine if it was herbivorous or carnivorous, and how it processed its meals medium-sized carnivorous dinosaur (for some smaller teeth, you may wish to use a dissecting scope). Note the overall shape as seen from the side as well as in cross-section. Look for any ridges or serrations.

7. Examine the jaws and beaks of the alligator snapping turtle, eagle, pheasant, and ostrich. The first two of these are carnivorous, while the latter two are herbivorous. What characteristics of their beaks might give a clue to diet?

8. Complete questions 9-13 on the worksheet as you refer to the skulls and teeth.

Quantification of Tooth Shape.

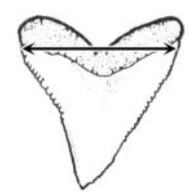
While some of the differences in tooth shape observed in lab are quite obvious, differences in shape can also be much more subtle. Detailed measurements can be used to characterize shapes and reveal differences that are not obvious with simple observation.

Such quantification also removes more subjective judgement and is thus more repeatable and testable.

We will measure teeth to compare tooth shape of two predator feeding styles: swallowing prey (such as fish) whole or slicing flesh. As you may have noticed, grasping teeth tend to be relatively slender and round in cross section, while slicing teeth are flattened laterally (side to side) to form blade-like edges. Since there is considerable variation in such shape, quantification of tooth shape can help resolve ambiguous cases. Since animals vary greatly in size, so too will their teeth vary in size. Therefore, absolute measurements of single dimensions are not very useful. For example, a tooth with a thickness of 3 mm could be very thin or very thick, depending on the overall size of the tooth. To compare among species, we instead want to use dimensionless indicators of shape. This is commonly in the form of the ratio of two measurements (more complex statistical procedures can combine many different measurements at once). To compare the ratio of the **width** (measured from front to back) to the **depth** (thickness, measured side to side), divide the width by the depth. A tooth that is perfectly round in cross section would have a **W:D ratio** of 1, while a narrow, blade-like tooth would have a W:D ratio that is much greater than 1.

Exercise 5: Quantifying Tooth Shape.

1. Use the electronic dial calipers to measure the length and width of various teeth that are loose or in skulls. The calipers give measurements in millimeters (mm).
2. Measure **width** from front to back at the widest part of the tooth (but not at any supporting bone), as shown by the arrow on the shark's tooth at right.



3. Measure the depth of the same tooth as the thickness from the inside to outer edge at its thickest point. We will not measure length.
4. For each tooth, calculate the width to depth (W:D) ratio by dividing the width by the depth.
5. Measure the teeth of a variety of modern animals, as indicated on your worksheet. For the teeth of dogs or coyotes, measure the triangular-shaped cheek teeth, as the slicing teeth and the long canines as grabbing teeth. Although the shark teeth are fossils, they are very similar in shape to comparable modern species.
6. Measure the fossil teeth of various carnivorous dinosaurs and determine the W:D ratio. Use the W:D ratio to determine their likely feeding style.

Name: ____________________________

Lab 8 Worksheet

Part 1. Prehistoric Plant Diversity.

1. Examine the various groups of plants available in lab and briefly describe their main characteristics here. Where applicable, note if extinct forms (based on fossils or models) seem to differ in a substantial way from the modern forms available in lab.

Plant Group	Describe overall growth form	Describe leaf shape	Describe texture (e.g. soft, tough)	Do fossils differ from modern forms?
Lycopod				
Horsetail		none		
Ginkgo	tree			
Fern				
Seed Fern			(Similar to fern?)	
Cycad				
Gnetophyte				
Conifer				
Flowering plant				

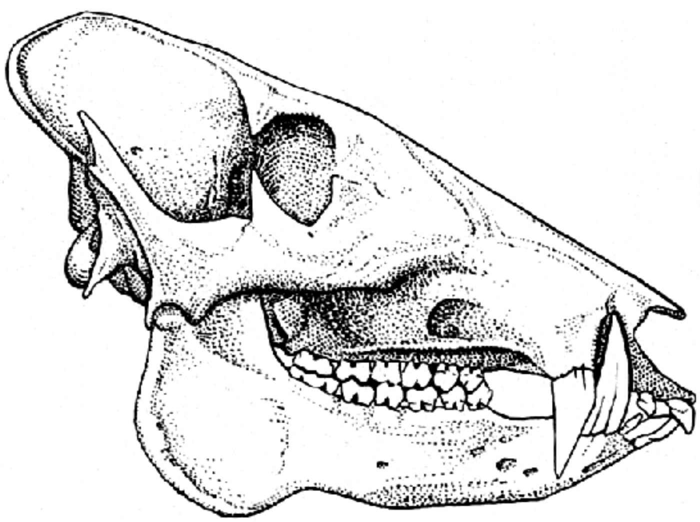
2. Plant nutritional value and digestibility is often related to how 'tough' a plant is. Soft, tender plants are typically of higher nutritional value and easier to digest than tough or fibrous plants (since the lignin and cellulose that make plants tough are largely undigestible). Based on your observations of the various groups of plants, which do you think were probably the best quality food source for herbivorous dinosaurs?

Name: ____________________________

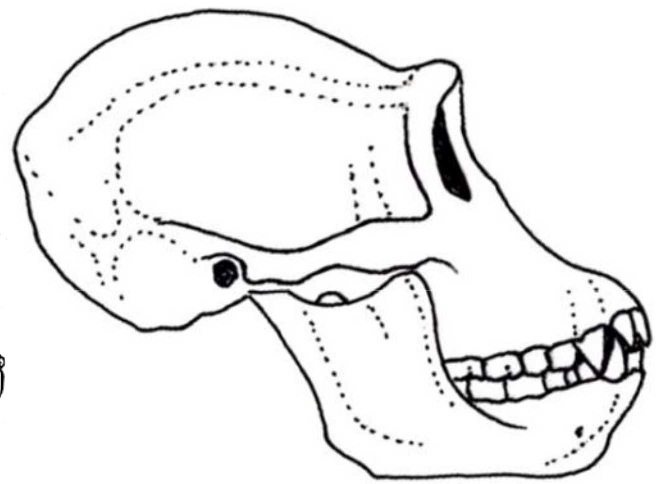
3. Which plants do you think were probably relatively poor food sources for dinosaurs?

Part 2. Diet and Skull Structure.

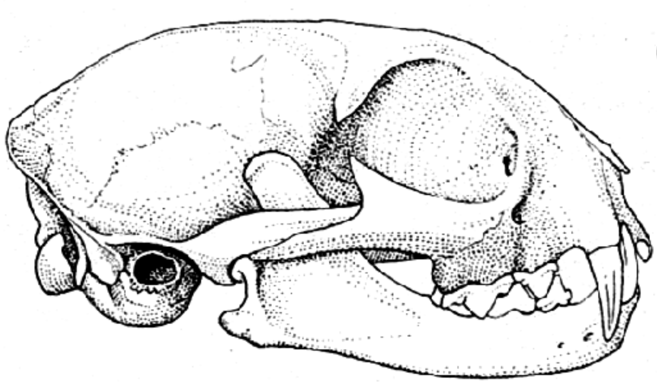
4. For each of the following skulls, indicate if you think the animal is a **carnivore**, **herbivore**, or **omnivore** based on its overall structure (tooth arrangements, jaw joint location). On each drawing, draw a straight line through the level of the tooth row and place an X at the point where the jaw articulates with the skull. Color in the key regions (if present) using the following color key:
   Blue = **grinding teeth**; *Green* = **diastema**; *Red* = **cropping teeth**



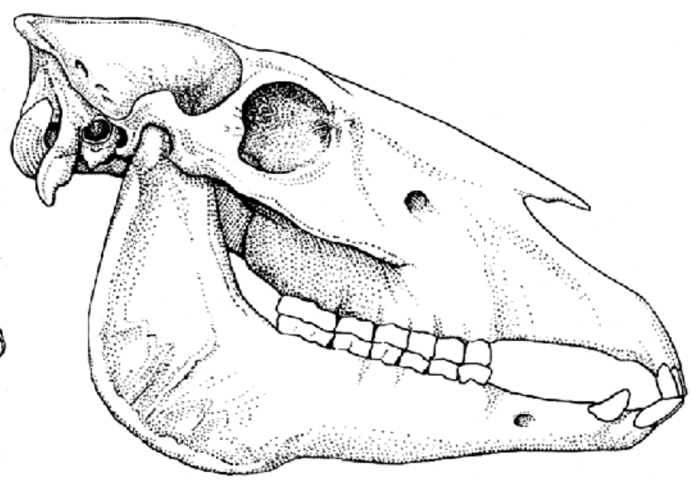
Peccary; diet = ______________________________



Chimpanzee; diet = ________________________



Bobcat; diet = ______________________________



Horse; diet = ________________________

5. Based on the characteristics of their **skulls** (small scale models), what do you think were the likely diets of the following dinosaurs?

Dinosaur	Diastema Present?	Jaw hinge is above/below/or at same level as tooth row?	Likely Diet (herbivorous or carnivorous)?
Allosaurus			
Ceratosaurus			
Cryolophosaurus			
Nigersaurus			
Oviraptor			
Pachycephalosaurus			
Styracosaurus or *Anchiceratops*			

Part 3. Grinding Surfaces and Dental Batteries.

6. Briefly describe or sketch the differences in the grinding surfaces of the teeth of a deer, a horse, and a rodent.

7. Sketch the appearance of a single tooth of the green iguana (your drawing should be larger than life size!).

8. In the space below, sketch the replica of *Edmontosaurus* jaw section so that you provide a lateral view. Label at least one each of the following on your drawing: **worn tooth**, **fresh tooth**, **replacement tooth**, and **grinding surface**.

Part 4. Diet, Feeding Style and Tooth Structure.

9. How do the teeth of a sea lion differ from that of their relatives, such as dogs and cats? How do you think sea lions eat their prey (chew it, swallow it hole, bite off chunks)?

10. Compare the tooth shapes of the three species of mosasaur available in lab with those of various modern predatory animals. For each, what do you think its likely diet was?

    Mosasaurus beaugei —

    Liodon anceps —

    Globidens aegypticus —

11. Based on your observations of various teeth above, what do you think the diet was for each of the following species represented by teeth in lab?

    Spinosaurus —

    Tyrannosaurus —

    Rebbachisaurus —

    Camarasaurus —

    Triceratops —

    Ankylosaurus —

Name: ____________________________

12. One of the species list in Question 11 also has its teeth arranged in batteries like hadrosaurs? Which do you think it is, based on tooth morphology? (Hint: consider tooth wear)

13. Based on your observations, what is one characteristic that may distinguish the **beaks** of carnivorous animals from those of herbivorous animals?

Part 5. Diet, Feeding Style and Tooth Shape.

14. Take a set of measurements from a single tooth of each of the "modern" species that slices its prey, as indicated in the table below. Calculate the W:D ratio for each species, and the range and mean W:D ratios for each feeding type.

Slicing Chunks Off Prey			
Species	Tooth width (mm)	Tooth depth (mm)	W:D ratio
Dog or coyote **cheek tooth**			
Water Monitor Lizard			
Serratolamna Shark			
Palaeocarcharodon Shark			
Otodus Shark			
Squalicorax Shark			
		Range (min–max):	
		Mean:	

15. Take a set of measurements from a single tooth of each of the modern species that swallows prey whole, as indicated in the table below. Calculate the W:D ratio for each species, and the range and mean W:D ratios for each feeding type.

Grasping Prey & Swallowing Whole			
Species	Tooth width (mm)	Tooth depth (mm)	W:D ratio
California Sea lion			
Pacific White-sided Dolphin			
American Alligator			
Nile Crocodile			
Dog or coyote **canine**			
		Range (min–max):	
		Mean:	

16. Take a set of measurements from each of the fossil (real or replica) dinosaur and mosasaur teeth listed in the table below. Calculate the W:D ratio for each species and by comparing to the data in Questions 14-15, determine the likely feeding style (swallowing whole or slicing) for each species.

Fossil Species				
Species	Tooth width (mm)	Tooth depth (mm)	W:D ratio	Feeding Style
Liodon anceps mosasaur				
Unid. Dromeosaur				
Spinosaurus				
Richardoestesia				
Tyrannosaurus				
Nanotyrannus				

17. Some paleontologists have suggested that *Nanotyrannus* may be juveniles of *Tyrannosaurus*. How do their tooth shapes compare and what does this suggest to you about the validity of this hypothesis?

Name: ____________________________

Lab 9 Worksheet

Part 1. Reptile Identification.

For each of the following prehistoric non-dinosaurian reptiles, describe one or two **morphological** characteristics that distinguish that reptile *from other members of the same group* (characteristics that can distinguish the different groups are given in the lab guide). You may use posture (such as if it has erect or sprawling limbs) only if it is a fundamental part of the design, but you should **not use** differences in poses that an animal would regularly take in life (such as if a pterosaur is standing or flying). **Do not use color** differences (since color is speculative). You may use size *only if all models in the group are made to the same scale*. For example, for *Dimetrodon* you should identify structural differences visible on the models that distinguish it from the other members of its group, *Edaphosaurus* and *Varanops*.

PELYCOSAURIA

Dimetrodon —

THERAPSIDA

Placerias —

Inostrancevia —

CYNODONTIA

Procynosuchus —

TESTUDINES

Odontochelys —

ICHTHYOSAURIA

Ichthyosaurus —

Shonisaurus —

LEPIDOSAURIA

Tylosaurus —

Name: ____________________________

Part 1. Continued

PLACODONTIA

Henodus —

PLESIOSAURIA

Liopleurodon —

Plesiosaurus —

Rhomaleosaurus —

Elasmosaurus —

BASAL ARCHOSAUROMORPHS

Champsosaurus —

Tanystropheus —

Euparkeria —

PHYTOSAURIA

Smilosuchus —

AETOSAURIA

Paratypothorax —

RAUISUCHIA

Postosuchus —

Arizonasaurus —

Name: ______________________________

Part 1. Continued

CROCODYLOMORPHA

Kaprosuchus —

Dakosaurus —

Sarchosuchus —

RHAMPHORYNCHOIDEA

Rharmphorhynchus —

PTERODACTYLOIDEA

Pterandon —

Anhanguera —

Tapejara —

Quetzalcoatlus —

Part 2. Convergent Evolution

Identify **three separate** examples of **convergent evolution** among the animals you observed in lab. Identify three *pairs* of species that share one or more distinctive morphological features, but whose evolutionary relationships suggest that morphological feature evolved independently. Be sure to list the convergent species and identify at least one feature they have in common:

Convergence Example 1:

Convergence Example 2:

Convergence Example 3:

Name: ______________________________

Part 3. Functional Interpretations

A. Among therapsids and cynodonts, *Inostrancevia*, *Trochosaurus*, *Procynosuchus*, and *Exaereto-don* are carnivorous while *Moshcops*, *Ischigualastia*, *Placerias*, *Dicynodon*, and *Lystrosaurus* are all herbivorous. Study the models of these animals and determine if there are any consistent morphological differences between the herbivores and carnivores (for example, do they tend to have different body shapes or postures or head size?)

B. Suggest a function for the distinctive shell of *Henodus* (Placodontia). With which modern animals is it convergent?

C. Which ichthyosaur had the largest eyes (relative to body size)? Why might it have had such large eyes?

D. Mosasaurs arrived in late Cretaceous and appeared to the take the place of some plesiosaurs which went extinct. Which Pleisiosaurs do you think they replaced (i.e., which were they most similar to)?

E. Ichthyosaurs went extinct in the middle Cretaceous and their ecological niche (role) may have been filled by one of the plesiosaurs. Which plesiosaur would have been most likely to have a diet similar to ichthyosaurs?

F. One of the the large semiaquatic Cretaceous crocodilians ate mostly fish, while the other hunted turtles and dinosaurs. What morphological differences between them is most likely to reflect this dietary difference? Explain why.

Name: ______________________________

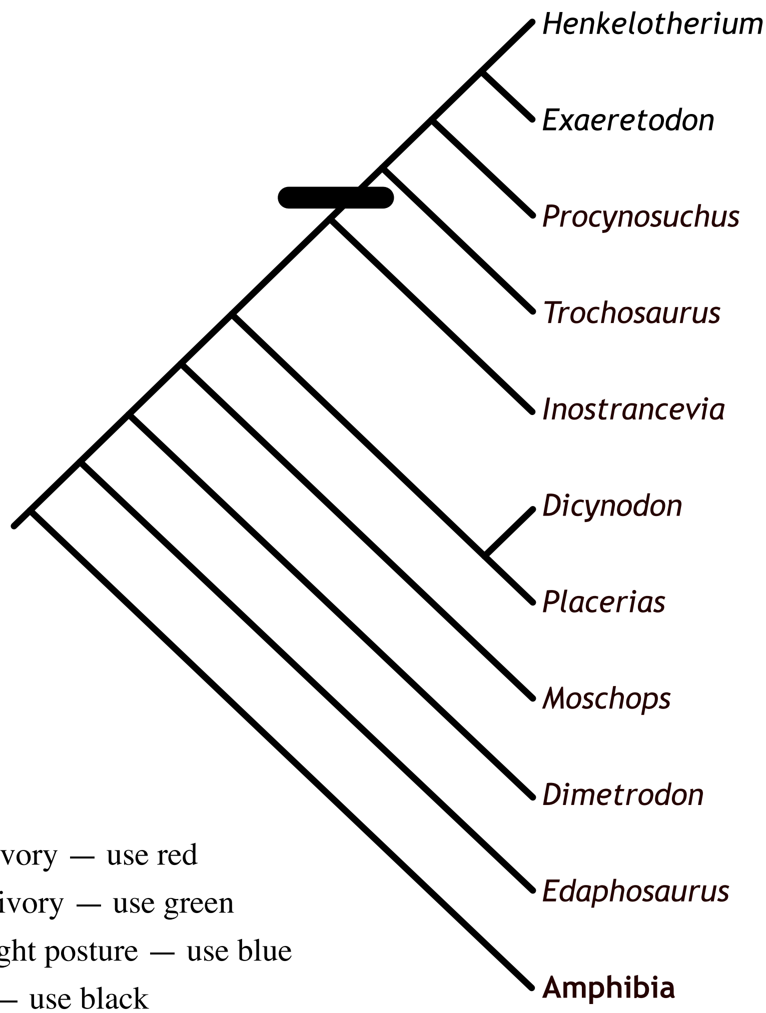
Part 3, continued

G. Compare the shape and posture of terrestrial crocodylomorphs such as *Montealtosuchus* and *Kaprosuchus* with semiaquatic species such as *Deinosuchus* and *Sarcosuchus*. Why does their body shape and posture differ?

H. Some of the Pterosaurs in lab, such as *Tupuxuara*, *Tapejara*, and *Pteranodon*, have prominant head crests. Suggest one hypothesis for the function of these head crests.

Part 4. Synapsid Evolution

The phylogenetic tree at right shows the evolutionary relationships of most (but not all) of the Synapsida that you observed in lab. For each of the characters listed below, indicate where on the phylogeny that character most likely evolved by marking a horizontal line in the indicated color at the appropriate branches on the phylogenetic tree. As an example, the origin of hair (as illustrated by the models, at least), is indicated by the black bar. Your evolutionary transitions should minimize the number of changes required, but some traits will nonetheless have evolved multiple times. Some transitions may not have occurred. Amphibia are the outgroup, and should be considered carnivorous.



Transitions:

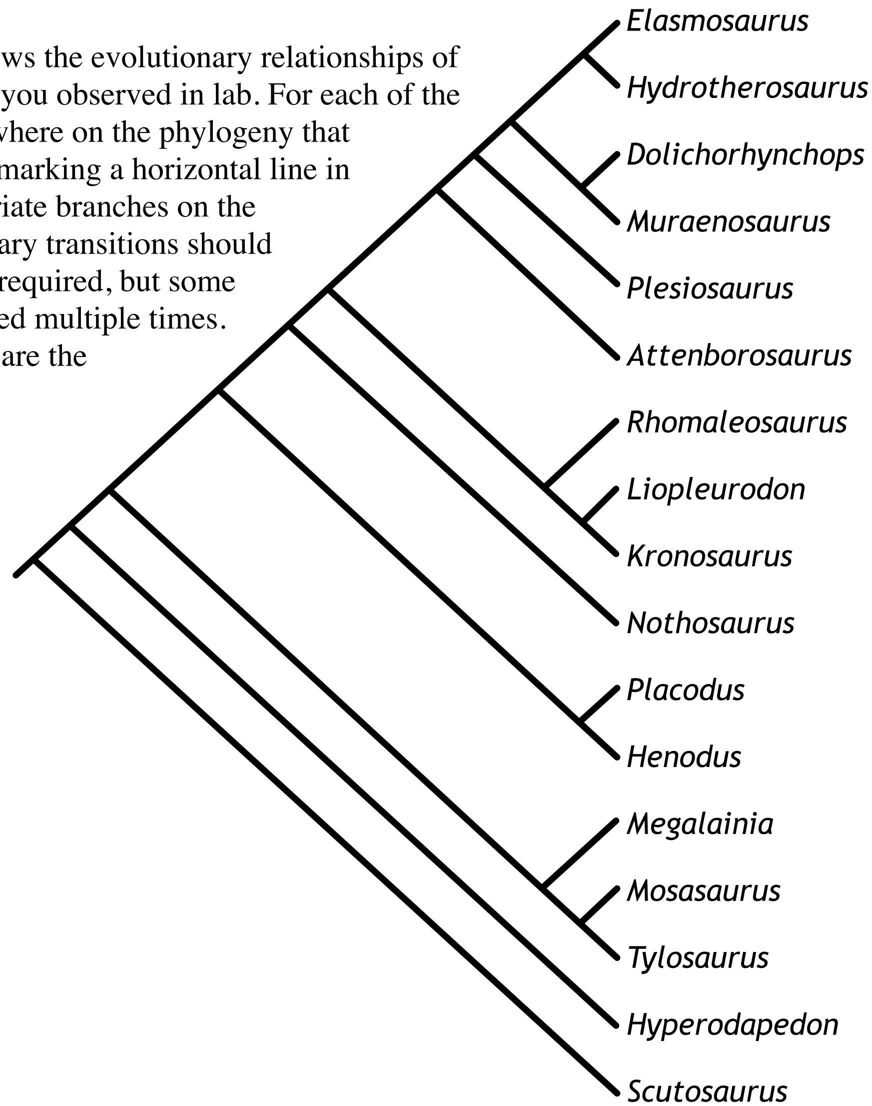
A. Transition(s) from herbivory to carnivory — use red
B. Transition (s) from carnivory to herbivory — use green
C. Transition (s) from sprawling to upright posture — use blue
D. Transition(s) from long to short tail — use black

Are the sail backs of *Dimetrodon* and *Edaphosaurus* likely to be homologous or analagous?

Name: ____________________________

Part 4. Diapsid Evolution

The phylogenetic tree at right shows the evolutionary relationships of selected Lepidosauromorphs that you observed in lab. For each of the characters listed below, indicate where on the phylogeny that character most likely evolved by marking a horizontal line in the indicated color at the appropriate branches on the phylogenetic tree. Your evolutionary transitions should minimize the number of changes required, but some traits will nonetheless have evolved multiple times. *Hyperodapedon* and *Scutosaurus* are the outgroups.



Transitions:

A. Origin of semi-aquatic habits (streamlined with webbed feet) — use purple

B. Origin of fully aquatic lifestyle (flippers instead of feet — use blue

C. Increased neck length — use red

D. Decreased neck length — use green

E. Increased head size (relative to body size) — use gray

F. Decreased head size (relative to body size) — use yellow

Name: ____________________________

Lab 10 Worksheet

Part 1. Dinosaur Identification.

For each of the dinosaurs, describe one or two **morphological** characteristics that distinguish that dinosaur *from other members of the same group*. **Do not use color** differences (since color is speculative). You may use size *only if all models in the group are made to the same scale*.

STEGOSAURIA

Stegosaurus —

Kentrosaurus —

Miragaia —

ANKYLOSAURIA

Minmi —

Edmontonia —

Polacanthus —

Ankylosaurus —

PACHYCEPHALOSAURIA

Pachycephalosaurus —

CERATOPSIA

Psittacosaurus —

Protoceratops —

Styracosaurus —

Triceratops —

Name: ____________________________

HYPSILOPHODONTIDAE

Hypsilophodon —

“IGUANODONTIA”

Tenontosaurus —

Iguanodon —

Ouranosaurus —

HADROSAURIDAE

Maiasaura —

Brachylophosaurus —

Edmontosaurus —

Parasaurolophus —

Corythosaurus —

PROSAUROPODA

Plateosaurus —

Name: ____________________________

SAUROPODA

Amargasaurus —

Nigersaurus —

Apatosaurus —

Diplodocus —

Camarasaurus —

Brachiosaurus —

Alamosaurus —

Part 2. Functional Interpretations

A. If species are too similar in their ecology and resource use, the intense competition may drive one or the other species extinct. Compare when most of the Stegosauria in lab lived to when most of the Ankylosauria lived. What does this suggest to you about how much the two groups would compete with each other if they co-occur?

B. Based on phylogeny and distribution of fossils, on which continent did ceratopsian originate? (Hint: on which continent are the most primitive or basal species found?) Did they migrate once or more than once to additional continents?

C. Of the six species of North American Ceratopsidae, what is the maximum number that co-existed at the same time?

D. Do the species of Ceratopsidae that occurred together 77-75 million years ago tend to be similar to each other (relative to the other Ceratopsidae) or do they look more different from one another? What does this suggest to you about the function of their horns and shields?

E. Do the species of Ceratopsidae that occurred together 68-65 million years ago tend to be similar to each other (relative to the other Ceratopsidae) or do they look more different from one another? What does this suggest to you about the function of their horns and shields?

F. Why might it have been especially important for *Leaellynasaura* to have large eyes? (Hint: consider its geographic distribution.)

G. How might Iguanodontians and Hadrosaurids have defended themselves against predators. Suggest at least two forms of predator defense as suggested by the fossil record for these groups?

H. Do basal, primitive sauropods (such as *Cetiosaurus*, *Spinophorosaurus*, *Shunosaurus*, and *Mamenchisaurus*) occur earlier or later in the geological record than the more derived Neosauropoda? Is this what you would have expected?

Name: ____________________________

I. The sauropods *Apatosaurus*, *Diplodocus*, *Camarasaurus*, and *Brachiosaurus* all coexisted in the same area around 150 million years ago. How might they have partitioned their resources to reduce the amount of competition? Indicate how or where each species most likely foraged.

Apatosaurus —

Diplodocus —

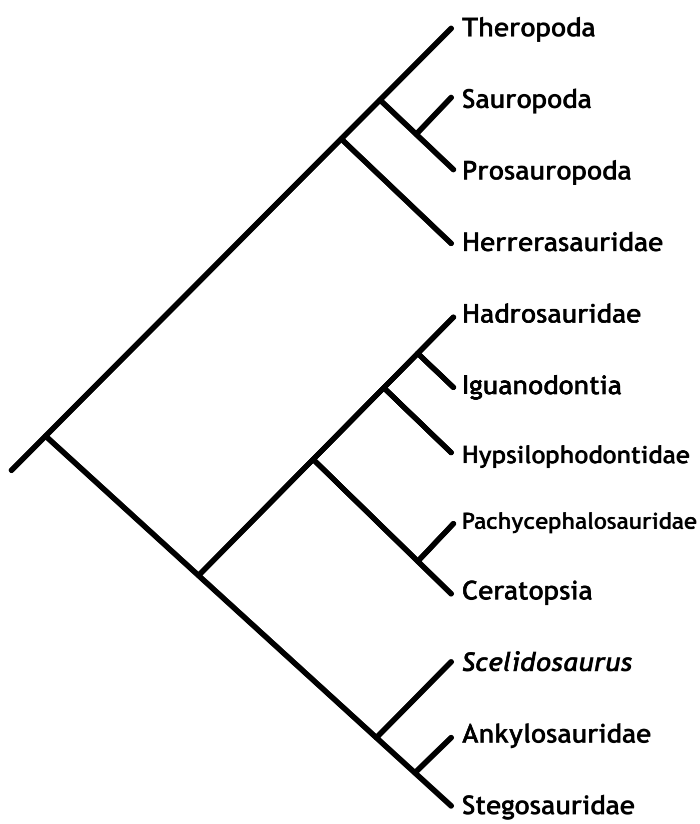
Camarasaurus —

Brachiosaurus —

J. Identify one characteristic shown on the models that distinguishes the sauropods known as Titanosauria (see phylogeny in lab guide) from other sauropods.

Part 3. Phylogenetic Patterns

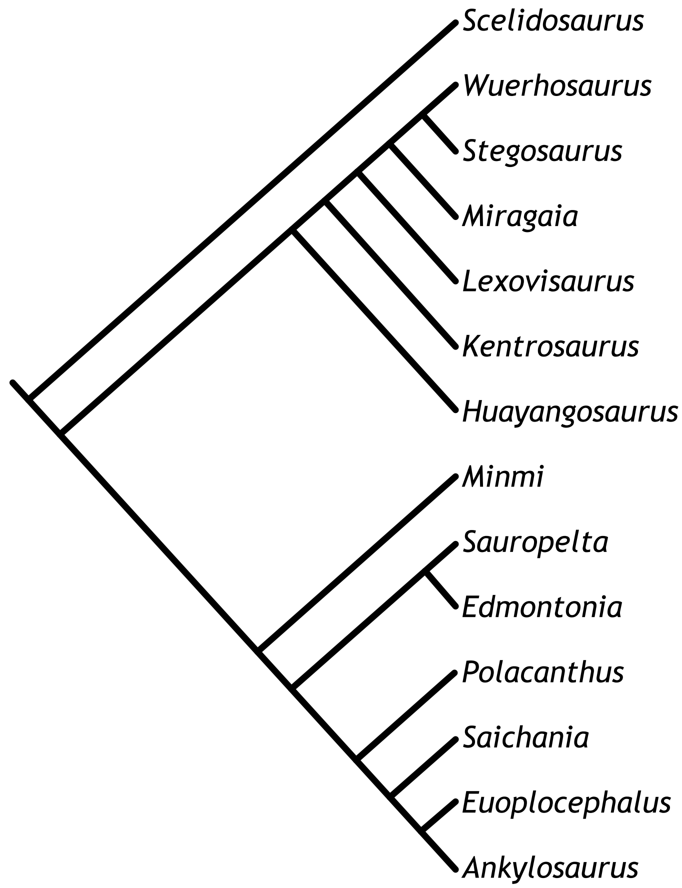
A. Assuming that the ancestral state for dinosaurs was to be bipedal and carnivorous (as in *Herrerasaurus*), indicate on the phylogeny at which points an herbivorous diet evolved (use green) and at which points a quadrupedal posture evolved (use blue). You should select the transistion points so as to minimize the number of required transitions while still correctly accounting for the distribution of diets. Remember that the Theropoda are also bipedal and carnivorous.



Name: ____________________________

B. On the phylogeny at right, indicate the following evolutionary transitions:

- Origin of tail clubs — use red
- Origin of tail spikes — use green
- Origin of shoulder spikes — use blue



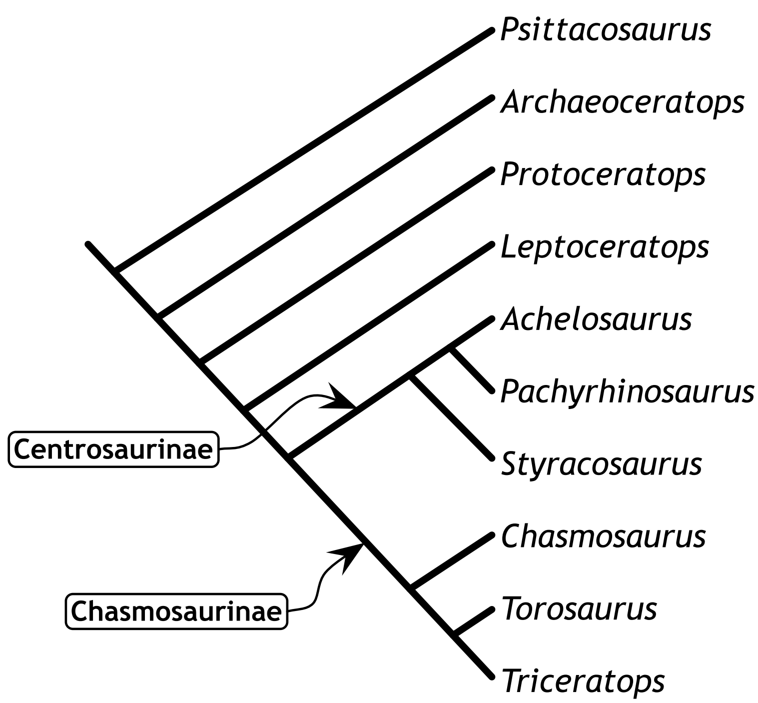
C. Based on the same phylogeny at right, is the lack of shoulder spikes in *Wuerhosaurus*, *Stegosaurus*, and *Miragaia* an ancestral or derived characteristic, compared to other stegosaurs?

D. On the phylogeny below right, indicate the following evolutionary transitions:

- Origin of enlarged head shield — use red
- Origin of nose horns — use blue
- Origin of brow horns — use green

E. On the same phylogeny at right, two subfamilies of Ceratopsids have been labeled. Identify at least one derived characteristic that distinguishes the subfamily Centrosaurinae

F. Identify at least one derived characteristic that distinguishes the subfamily Chasmosaurinae



Name: ____________________________

Lab 11 Worksheet

Part 1. Dinosaur Identification.

For each of the dinosaurs, describe one or two **morphological** characteristics that distinguish that dinosaur *from other theropods*. **Do not use color** differences (since color is mostly speculative). You may use size *only if all models in the group are made to the same scale*.

HERRERASAURIDS

Herrerasaurus (compare to basal theropods such as Coelophysoids) —

COELOPHYSOIDS

Coelophysis —

Dilophosaurus —

CERATOSAURIA

Carnotaurus —

Ceratosaurus —

"CARNOSAURS"

Allosaurus —

Giganotosaurus —

Acrocanthosaurus —

Concavenator —

Megalosaurus —

Name: ____________________________

SPINOSAURIDAE

Spinosaurus —

Baryonyx —

COMPSOGNATHIDAE

Sinosauropteryx —

TYRANNOSAUROIDEA

Guanlong —

Dilong —

Alectrosaurus —

Tyrannosaurus —

ORNITHOMIMIDAE

Gallimimus —

OVIRAPTOSAURIA

Oviraptor —

Caudipteryx —

THERIZINOSAURIDAE

Therizinosaurus —

Nothronychus —

Name: ______________________________

DEINONYCHOSAURIA

Velociraptor —

Deinonychus —

Microraptor —

Anchiornis —

Part 2. Functional Interpretations

A. Suggest a function for the head crests (composed of thin bone but probably covered in keratin) for the dinosaurs *Dilophosaurus* and *Cryolophosaurus*.

B. Why do you think several large theropods such as *Carnotaurus* and *Tyrannosaurus* have such reduced forelimbs?

C. Study the heads and especially the snouts of *Spinosaurus* and *Baryonyx*. What animal from a previous lab do these most closely resemble? What does this suggest their diet may be?

D. Which dinosaurs from a previous lab do the Therizinosaurs (especially *Therizinosaurus*) most resemble in overall shape and posture? What does this suggest about their diet?

E. Suggest **two** functions for the elongated claws of Therizinosaurs such as *Nothronychus*.

F. *Tyrannosaurus* had a powerful, heavily built skull (more robust than that of other similar sized carnivores such as *Spinosaurus* or *Giganotosaurus*) and teeth that were rounder in cross section rather than flattened. What does this suggest to you about what and how it ate?

G. What does the greatly enlarged toe claw of dromeosaurs such as *Deinonychus* suggest about the type and size of prey that it normally consumed? Explain your reasonging.

H. Examine the feathers on the arms and tails of dinosaurs such as *Caudipteryx* and *Oviraptor*. Their arms are far too short to have an aerodynamic function, so what other function might these feathers have?

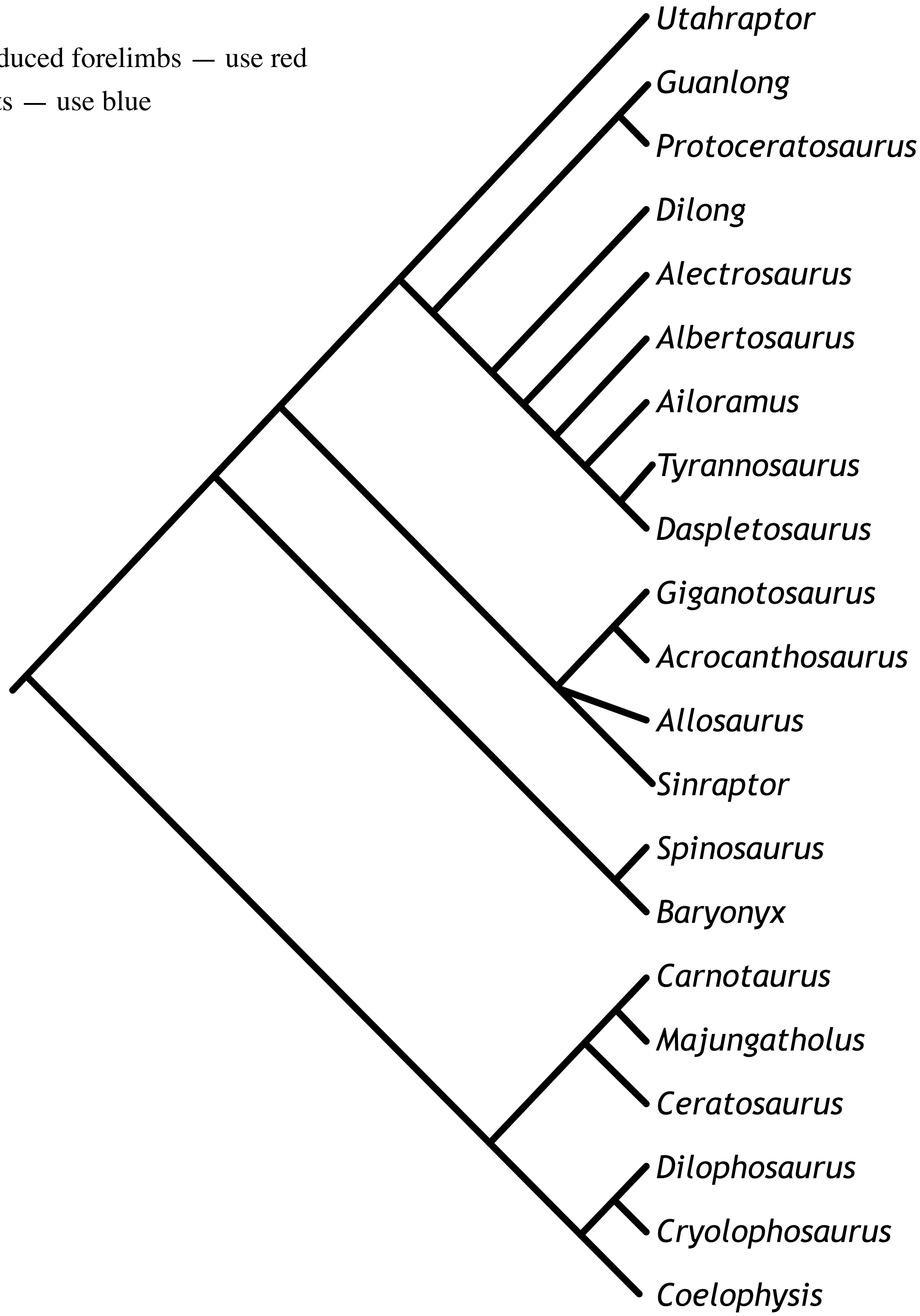
I. Microscopic analysis of feathers from two dinosaur fossils has revealed their likely color pattern in life. Models of both of these species are present in lab. Locate and identify these species. Based on the color of the model or photograph (as appropriate), what do you think the function of their color patterns was?

Name: ______________________________

Part 3. Phylogenetic Patterns

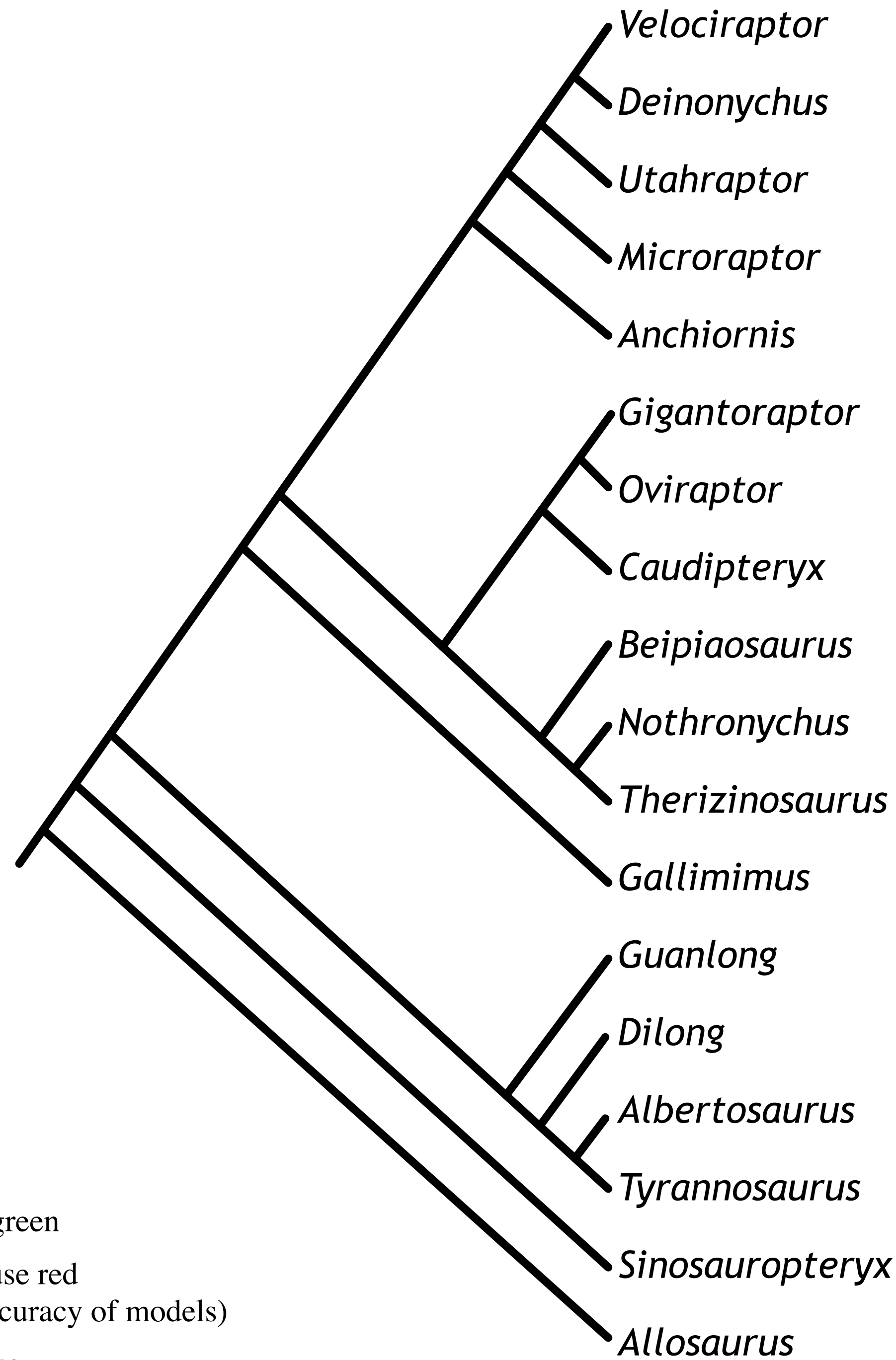
A. Assuming that *Herrerasaurus* (not shown on the phylogeny) represents the ancestral state, indicate on the phylogeny at which points the following characteristics evolved. You should select the transistion points so as to minimize the number of required transitions while still correctly accounting for the distribution of traits.

- Origin of greatly reduced forelimbs — use red
- Origin of head crests — use blue



Name: ____________________________

B. On the phylogeny at right, indicate the following evolutionary transitions:



- Origin of herbivory — use green
- Origin of slashing claw — use red
  (Hint: be sure to verify accuracy of models)
- Origin of feathers — use blue
  Hint: feathers are a complex trait that likely evolved only once, so indicate the most recent possible point of origin; the lack of feathers on models is not necessarily evidence of lack

C. Name **four** dinosaurs that should have feathers based on their phylogenetic position but were not reproduced as being feathered.

Lab 13 — Dinosaur Size and Allometry

Introduction.

Body size is one of the most important of biological variables, and reaches its most extreme size in dinosaurs. Body size affects the amount of food an animal needs, how fast it can move, how much heat it generates, and how it supports itself. Some of the impacts of size relate to how different aspects of three dimensional objects scale. Thus, it is of considerable importance to know how big dinosaurs were in life.

Unfortunately, we don't have dinosaurs in the flesh, so it is not possible to directly weigh dinosaurs. Instead, paleontologists have developed several techniques to estimate their weight based on their skeletons. These techniques require researches to make numerous assumptions, so there can be considerable variation in the estimates provided by different researches, depending on the kinds of assumptions they make. It is an art as much as a science.

The main technique to estimate dinosaur mass involves determining the volume of the dinosaur. Traditionally, this was done using scale models made by professional sculptors working with a scaled down replica of the skeleton. The modeler would apply the probable arrangement of muscles and other tissue to produce a three-dimensional replica. The volume can then be determined by the displacement of water. More recently, a version of this technique is done using virtual models build with 3D computer software. The accuracy of this technique is dependent on both the accuracy of the scale model and accuracy of the estimate of dinosaur densities. We will be using this technique with some of the scale models of dinosaurs that we had in class.

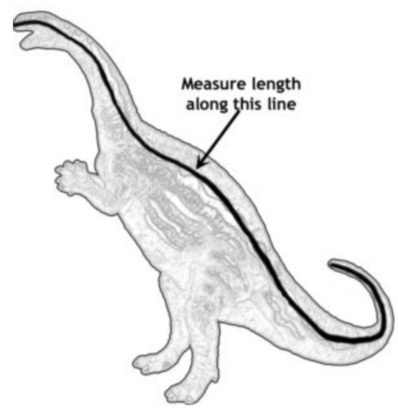
The second method involves extrapolation from the size of the limb bones. Dinosaurs must support themselves on their legs, and the bigger the dinosaur, the more massive the leg needed to support the dinosaur. Large animals need proportionately thicker legs than do small animals. This is because as the length of an animal increases, its mass increases by the cube of the length increase, but the strength of bone only increases by the square of its diameter (since strength is determined by its cross-sectional area). In order for bone strength to keep up with mass, bones must get proportionately thicker in larger animals. By measuring the diameter of the dinosaur's bones, one can extrapolate from living animals to estimate how much weight they supported. Of course, this assumes that bone strength is directly proportional to its cross-sectional area, and that the animals are using their limbs in a similar fashion. However, large animals may be less agile or active, and thus apply less stress to their legs.

Part 1 — Determining the Scale of Models.

In order to be able to extrapolate from dinosaur models, we must first determine the scale of the model. Scale is based on linear dimensions, that is lengths. Scale is usually written as a fraction, such as $^1/_{20}$, but can sometimes be written as a ratio, e.g. 1:20. For example, a $^1/_{20}$ scale model of a 10 m long dinosaur would be 0.5 m long. To determine the length of an actual dinosaur based on a model of known scale, simply divide the length of the model by its scale. Thus, a 20 cm long model that is 1/50 scale would represent a dinosaur that is (20/0.02 =) 1000 cm or 10 m long.

Since many manufacturers do not make models to a specific scale, and even when they do it may vary, we will need to determine the scale of each model. We will do this by comparing the length of the model to the length of the actual dinosaur, as estimated from fossils (even lengths are rarely certain since most fossil skeletons are incomplete as well as uncertainty about soft tissue such as vertebral disks). One challenge will be to control for the effect of the body positions of the models. The published lengths are the lengths of the axial skeleton, from the snout to the tip of the tail with the animal straightened out. Most models, however, have more varied poses, with the neck and tail bent or curled. Thus, to measure the models, it is important to measure roughly along the the vertebral column rather than a straight-line length (see Figure 1).

Figure 1. *Measure dinosaur length along the black line*



Exercise 1: Determining Scale.

1. You and your lab partner should obtain **five** different dinosaur models. Try to get models that represent a diversity of clades.
2. Measure your model along its vertebral column, from the snout to the tail tip, as if it were straight. One useful technique is to use a soft wire that can conform to the animal's shape and then be straightened out to measure against a ruler. Extra long twist ties or pipe cleaners work well for this. Hold the wire or similar at one end of the animal, and lay it against the side of the model along its length, bending it as necessary to conform to the shape of the model (see above figure). Mark the spot on the wire where it reached the opposite end of the model, either with your fingers or by sharply bending the wire at that point.
3. Straighten the wire and measure the length to the point you marked using a metric ruler.
4. Convert the model's length from centimeters or millimeters into meters.

5. Look up the actual length of the dinosaur, in meters, using the tables from T. R. Holz 2007 *Dinosaurs* encyclopedia (Random House). The tables in lab are updated tables that are posted online and were last revised December 2010.

6. To determine scale, divide the length of the dinosaur (in meters) by the length of the model (converted to meters). This gives you the denominator of the scale. Round to the nearest whole number.

7. Record your data in Question 1 of the worksheet.

Part 2 — Estimating Mass by Volume Displacement.

We will estimate the volume of the models using the displacement of water. By measuring the amount of water displaced by a fully submerged model, we can determine the volume of the model. Since the scale of the model is based on a linear measurement, the volume will scale to the linear scale raised to the third power. Thus, if a $^1/_{20}$ scale model has a volume of 50 ml, the volume of the actual dinosaur would be 50 ml x 20 x 20 x 20 or about 400,000 ml (400 liters). Finally, volume can be fairly easily converted into mass, since most vertebrates are typically slightly less dense than water: about 0.95 g/ml, and we will assume that dinosaurs were similar. (It is possible that theropods and sauropods, with their extensive air sacs, were a bit less dense, while heavily armored dinosaurs like ankylosaurs were a bit more dense than this.) This method assumes that the shape of the models, such as the thickness of legs or neck or tail, is fairly accurate. While models created by paleontologists reflect the latest thought about muscle arrangements and other tissues, the replicas we use in class will not be that accurate, and compromises for strength and aesthetics may have been made.

Exercise 2: Estimating Dinosaur Mass.

1. Use the same five dinosaurs for which you estimated the scale.

2. At the sinks in the lab are large bottles with a tube emerging from the side, and in the sink should be a graduated cylinder.

3. Using a beaker, fill the bottle until water starts coming out of the side tube (make sure the spout points into the sink!).

4. Once water is no longer flowing out of the tube, place an *empty* graduated cylinder beneath the tube opening so that it catches any water coming out.

5. Gently submerge the model in the bottle of water so that it is completely submerged. Avoid splashing or making waves.. No part of the model should be out of the water, and your hands or other objects should not be submerged. It may

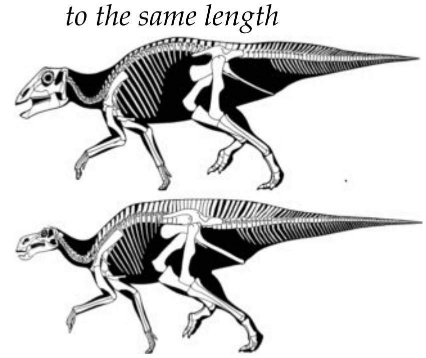
help to use the eraser end of a pencil to hold the end of the model just below water level.

6. Examine the graduated cylinder to determine how much water was displaced. You should read the volume of the cylinder before removing the dinosaur from the bottle (since this can cause extra water to spill out). If the cylinder overflowed, or if any water spilled out, you will need to repeat Steps 3-5.
7. Record your results for Question 2 of the worksheet.
8. Repeat the procedure for each of your dinosaurs, being sure to refill the bottle and empty the graduated cylinder between each.
9. Determine the volume of the actual dinosaur by multiplying the volume of the model by cube the inverse (denominator) of its scale. Thus, the volume of a $^1/_{20}$ scale model should be multiplied by 20^3 to obtain the volume of the dinosaur in ml.
10. To convert the volume of the dinosaur to mass, multiply your volume (in ml) by 0.95 to obtain their weight in grams.
11. Convert grams into kilograms by dividing by 1000 g/kg. This is your estimated weight.
12. Record your results on the worksheet. You will then need to compare your results to those that have been made by paleontologists. You can use internet resources and books to locate these values. It may be helpful to know that one ton (US) is 907 kg, although the use of ton (or tonne) in the scientific literature usually refers to a "metric ton" or 1000 kg.

Part 3 — Dinosaur Allometry.

Everything about the biology of an animal is influenced by its body size, including its physiology (e.g., heart rate, respiratory rate, metabolic rate, growth rate), anatomy (e.g., organ mass, blood volume, surface area), and ecology (e.g., diet, home range size, life span, population density). As organisms increase in size, either during individual development or in the evolution of a species, the size and function of different parts typically grow at different rates. Such a difference in shape associated with changes in size is called **allometry**. The opposite of allometry is **isometry**, where changes in size produce no changes in shape or proportions. For example, the dinosaur models are (hopefully) isometric

Figure 2. *Juvenile and adult* Maiasaura *skeletons scaled to the same length*



representations of the adult form of dinosaurs. On the other hand, dinosaur growth is allometric: juveniles tend to have proportionately larger heads and eyes and shorter limbs than adults, as seen in *Maiasaura* (Figure 2).

Figure 3. *Maiasaura and Othnielosaurus skeletons, rescaled to the same length*

Similarly, species tend to show allometric variation as well. Compare the skeletons of two Ornithopods, *Maiasaura* (2500 kg) and *Othnielosaurus* (30 kg) (Figure 3). When the skeletons are drawn to the same length, the differences in shape are obvious, with *Maiasaura* having a proportionately larger head, shorter neck, longer arms, deeper body, shorter tail, and thicker legs.

Overall, the study of allometry is the study of how one variable changes as another, such as size, does. The general equation for allometric relationships is: $Y = aX^z$. The letter a indicates a constant that essentially converts X to Y (it can be used to convert among different units of measurement, for example). The exponent z is the **scaling factor**: it indicates how much faster (or slower) one variable (Y) changes in response to changes in the other (X). Unfortunately, unless the exponent z is 1 (which indicates isometry), the relationship between X and Y will a curved line instead of a straight line. (For example, in scaling the model size (Y) to actual dinosaur size (X), a would be the model's scale, while z would be 1.)

Since curved lines are more difficult to describe and visualize mathematically, we can alter the equation to form a line by taking the logarithm of both sides:

$\log Y = z \bullet \log X + \log a$

Note that log a is still a constant (the intercept of the line), so we can replace it with another letter, such as m. If we plot log Y against log X, we will obtain a straight line with slope z, the scaling factor. Instead of taking logarithms, we can plot X and Y on a logarithmic scale (which can easily be done in software such as *Excel*.

The allometric relationship that we will study in this lab is the relationship between body mass and leg size. The strength of an animal's bones is related to the bone's cross-sectional area. The cross-sectional area of a bone is related to its diameter by the equation $^{\pi}/_{2}r^2$. Note that $^{\pi}/_{2}$ is the constant a in the allometric equation, while the scaling factor is 2. An animal's mass (and thus the strength needed to support it) increases with the volume, which is a cube of linear size ($z = 3$). For example, imagine two dinosaurs of identical *shape*, but in which the larger is twice the length of the smaller. The larger dinosaur would have 4 times (2^2) the cross-sectional area of its leg bones, but would have 8 times (2^3) the volume, and thus mass. Thus, its leg bones would be inadequate to support its proportionately greater mass. This means that as animals increase in size, they cannot simply be scaled up from small to large, but instead need proportionately thicker legs. This relationship is complicated by the fact that larger animals tend to undergo fewer strenuous activities, such as running or jumping, that puts stress on the bone, and thus they would not need quite as thick legs as their mass would suggest.

In mammals, for example, the the relationship between mass and leg diameter (a linear measure of size) is as follows:

$$\text{mass} = a(\text{leg diameter})^{2.63}$$

Note that the scaling factor (exponent) is less than 3, indicating that leg diameter does not increase as rapidly as expected based on the geometric increase in volume/ mass. This is because large animals such as elephants do not gallop and jump in the way a small gazelle might and thus puts less stress on its legs relative to body size.

Since we do not have dinosaur leg bones available in lab for study, we will once again use models to test the relationship between leg size and body mass in dinosaurs (and thus assume that the legs of the models adequately represent the thickness of the legs and leg bones of dinosaurs). By plotting the relationship between body mass (based on your estimates from above) and leg diameter (which you will measure), we can determine the exponent of the relationship between these variables. Conversely, if we know the relationship between leg diameter and mass for dinosaurs as a whole, we can estimate the mass of dinosaurs known from just single leg bones.

Exercise 3: Measuring Leg Diameter.

1. The analysis will require the use of the class data, but each group is responsible for the same five dinosaurs examined in Exercise 2.
2. For each dinosaur, determine if it is primarily quadrupedal (the Sauropods and most Ornithischians except the Hypsilophodontids) or bipedal (Prosauropoda and Theropoda).
3. Using calipers, measure the diameter, in mm, of the hind leg at the middle of the lower leg (the tibia). (Normally, the femur is measured but as this segment is much more muscled, there is greater potential for variability when measuring models rather than bones).
4. If the dinosaur is quadrupedal, also measure the diameter of the forearm (ulna and radius).
5. Add the diameters for each of the 2 (bipedal) or 4 (quadrupedal) limbs together to obtain the total limb diameter.

6. Convert the model diameter to the diameter of the actual dinosaur limb by dividing by the scale (or multiplying by the denominator of the scale). Convert mm into centimeters.
7. Record the data for leg diameter in Question 7 of your worksheet.
8. Enter the data for the dinosaur (not model) mass and total limb diameter on the *Excel* spreadsheet on the class computer. These data will be posted tonight on the course web page.

Exercise 4A: Analyzing The Relationship Between Leg Diameter and Dinosaur Mass.

1. This analysis will require the use of the class data which will be available as an *Excel* file on the course web page.
2. If not already done, enter the data in columns, with each row representing one species (species data must be aligned across rows). The two data columns are total leg diameter and mass of the dinosaur (not the model).
3. Highlight the two columns of numerical data and select the **XY Scatterplot** graphing option, specifically the option without lines. You should get a graph with the diameter on the X-axis and the mass on the Y axis. In all likelihood, the points will not form a straight line but instead have a J-shaped relationship. Go through the various option panes, which allow you to label axes, position your graph, etc.
4. When your graph is completed it will have points but not a best-fit line to illustrate the relationship. To add this, right-click or option-click on one of the data points and select "**Add trendline**" from the menu.
5. Under the "**Type**" tab, select the **Power** option. Then select the "**Options**" tab and click the "**Set intercept**" button (keep it set to 0), the "**Display equation**" button, and the "**Display R-squared value**" button.
6. If all goes well, your graph should have a curved best-fit line along with the equation for that line, in the format of: $Y = aX^z$, where a and z are represented by specific numbers. Y represents the dinosaur's mass, while X represents the total leg diameter. The number in front of the X is the constant a which serves to, among other things, convert units (cm to kg); we will not concern ourselves with this.
7. The key number in this equation is the scaling factor (the exponent to which X is raised). Ideally, this will be a number between 2 and 3. A 2 would indicate that mass is increasing as a square of the leg diameter. Since the leg diameter is linear, and mass is dependent on volume, this is lower than what we would expect. If the exponent is 3, this means that mass increases as the cube of leg diameter

which would be expected if stresses on the leg increased directly proportional to the mass. In mammals, the exponent is 2.63 since large animals engage in less limb-stressing activity such as jumping.

8. The final number of interest is the R^2 value. This is a statistical measure that determines how strong our data are: how well the points fit the line. R^2 ranges from 0-1, with 0 meaning no relationship at all and 1 meaning the points fall perfectly on a line. The R^2 value determines the proportion (multiply by 100 to convert to %) of the variation in body mass that can be explained by variation in leg diameter. The higher the R^2 value, the more confidence we can have in our equation.

Exercise 4B: Alternative Analysis of The Relationship Between Leg Diameter & Dinosaur Mass.

1. As an alternative to the analysis above (if you are having trouble with *Excel*) is to take the logarithms of mass and leg diameter and plot these on the graph instead of the actual masses and diameter.
2. Collect your data as described above. You will need to plot and analyze these data with *Excel* as described above, but in this case you should select the **linear** trendline option. In this case, the number *before X* is the scaling factor.

Name: ______________________________

LSC 294 — Dinosaurs
20 points

Lab 13 Worksheet

Part 1. Determining Scale

1. Record the data and calculations from your estimates of dinosaur mass in the table below.

Species	(a) Model Length (cm)	(b) Model Length (m)	(c) Dinosaur Length (m)	(d) Model Scale $\frac{1}{(c/b)}$

Part 2. Estimating Dinosaur Mass

2. Record the data and calculations from your estimates of dinosaur mass in the table below.

Species	(d) Model Scale	(e) Volume of Water (ml)	(f) Volume of Dinosaur $(e)(1/d)^3$	(g) Mass of Dinosaur (g) 0.95(f)	(h) Mass of Dinosaur (kg) (g)/1000

3. Obtain at least two separate scientific estimates of the mass of each your dinosaur species. List these estimates and the sources of information in the table below.
   For books or print articles, give the author's name, title of book, and year published.
   For web sites, give the name of the site and the URL of the page with the information.
   Mass estimates should be in kg. If given a choice, use the average mass rather than the largest known individual.

Species	**Source** (Give two per species)	**Mass estimate (kg)**

4. Do the body mass estimates from the two sources tend to agree with each other or are they different. If different, what may account for this difference?

5. How close were your estimates of mass compared to those done by professional paleontologists?

6. What are at least two reasons why your estimates differed from published or online estimates?

Part 3. Dinosaur Allometry

7. Record the leg diameter data in the table below. Record the data from Question 1, column h and this question, column l on the *Excel* spreadsheet on the class computer.

Species	**(d) Model Scale**	**(i) Model Hindlimb Diameter**	**(j) Model Forelimb Diameter**	**(k) Total Model Limb Diameter 2i (+2j)***	**(l) Total Dinosaur Limb Diameter k/d (cm)**

* use forelimb data only for quadrupedal species

8. Plot the relationship between dinosaur mass and leg diameter (or alternatively, between log(dinosaur mass) and log(leg diameter)) using *Excel*. Attach the printout of the graph as a separate page. Be sure to include the best-fit line (trendline).

9. Write the equation for the curve or line from the graph in Question 8:

10. What is the scaling factor that you obtained from the relationship between dinosaur mass and leg diameter?

11. Is the scaling factor what you expected or is it too large or too small? If it is not what you expected, what might account for this deviation?

12. What was the R^2 value for the data you plotted in Question 8? What can you conclude about the reliability of your estimates for the scaling factor?

Lab 15 — Human Evolution

Introduction.

Humans are not dinosaurs, of course, and did not live with dinosaurs. Nonetheless, it can be informative to study our evolution to gain a better understanding of the evolutionary process and how we interpret the fossil record. Because of the interest in our own ancestry, much effort has gone into finding human fossils. Thus, we have a great deal of evidence that is resolved at much finer levels of time and space than is typically possible for dinosaurs.

Humans belong to the **Class Mammalia**, **Order Primates**, and so we will begin our study of human evolution with a brief survey of primate diversity. Humans exhibit many distinctive features that distinguish us from the closely related apes, such as bipedalism, very large brain, and reduced body hair. In this lab we will explore the diversity of our extinct and extant relatives.

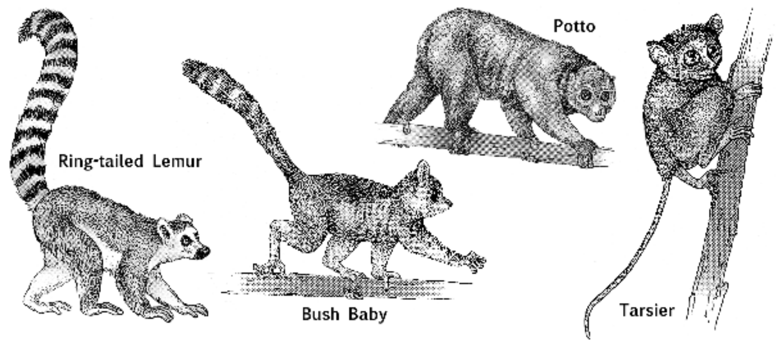
Part 1: Primate Diversity

Primates have an arboreal (tree-dwelling) lifestyle and many of their characteristics are adaptations to that lifestyle. Key features associated with climbing include grasping hands and feet with flexible thumb and toe for grasping, flat nails rather than claws on at least some (and usually all) digits, shoulder and elbow joints that permit a high degree of forelimb rotation, and large, forward-facing eyes that provide binocular vision. Primates tend to be omnivorous or fruit-eaters, and thus have squarish molars with rounded bumps. Their snouts are usually shortened. Primates have large brains and usually complex social behavior; parental care is extensive and thus primates usually only have one or two offspring at a time.

The first primate fossils date from the late Cretaceous period. These primates were small, squirrel-like mammals (probably somewhat like the modern tree shrews). Traditionally, primates were divided into two groups, the prosimians and the anthropoids. The **prosimians** are anatomically primitive and generally show less extensive development of the primate features. The **anthropoids** are the more derived monkeys and apes. Although the anthropoids make up a monophyletic group, the prosimians are paraphyletic and this grouping, while still convenient, is no longer used in formal classifications (instead, primates are formally divided into the Strepsirhini and Haplorhini). Since the study of primates is only incidental to the topic of this course and we have limited material available, we will stick with the traditional sub-divisions of prosimians and anthropoids.

The prosimians (Fig. 1) tend to have smaller brains and longer snouts than the anthropoids, and most are relatively small. Key distinguishing features are the presence of nostrils surrounded by moist skin and lower incisors modified into a tooth comb. This group includes lemurs, bush babies, and lorises that occur in Africa, Madagascar, and Asia.

Figure 1. *Examples of various "prosimians."*



The anthropoids have nostrils surrounded by dry, hairy skin, blade-like incisors, a shortened snout and the back of the orbit is composed of a bone wall. This group includes the marmosets, monkeys (Fig. 2) and apes (Fig. 3).

Figure 2. *Examples of various anthropoid "monkeys."*

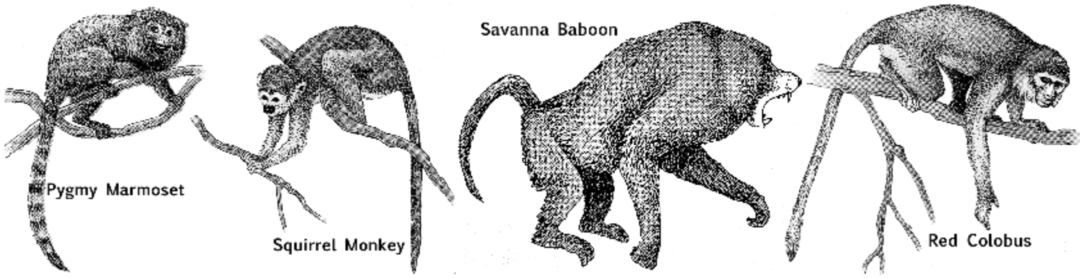
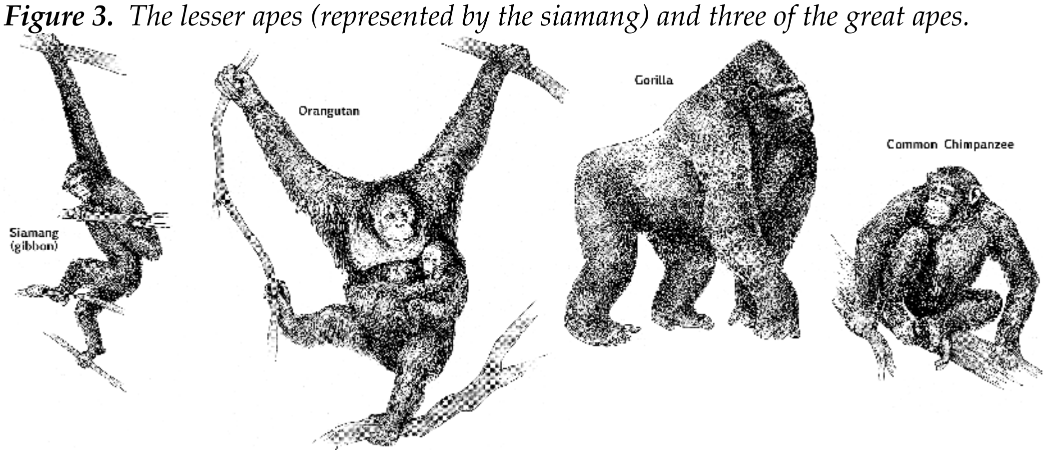


Figure 3. *The lesser apes (represented by the siamang) and three of the great apes.*



The **apes** (Fig. 3) are a derived subgroup of athropoids characterized by a relatively large size and loss of the tail. There are two groups of apes. The lesser apes are the gibbons. They are smaller and move about by swinging from their arms. The great apes are larger and include the orangutan (*Pongo pygmaeus*) from southeast Asia and the gorilla (*Gorilla gorilla*), chimpanzee (*Pan troglodytes*) and bonobo (or pygmy chimp, *P. paniscus*) from Africa.

Exercise 1: Primate Diversity.

1. Study the photographs of the various primate groups presented on the course web site.
2. The bush babies and lemurs are examples of prosimians. Look for primate features such as forward-facing eyes and opposable toes. Look closely for prosimian characteristics such as a proportionately smaller head and a narrow, protruding snout.
3. Examine the skull of a ruffed lemur, *Varecia variegata*. Note its relatively elongated shape. Look at the back of the orbit to see that it is open (as is typical of most mammals). The lower incisors (front teeth) project directly forward to form a grooming comb, a characteristic of most prosimians.
4. Compare the prosimians to the photographs of the Anthropoidea, the monkeys and apes. Look for the larger head and shortened snout in most anthropoids (although a long snout has secondarily evolved within the baboons, a group of terrestrial Old World monkeys). Look closely to see that the anthropoid nose lacks a moist pad and is usually hairy.
5. The remaining skulls all represent members of the the Old World monkeys and apes. In particular, compare the skull of a vervet monkey (*Cercopithecus aethiops*) and hamadryas baboon (*Papio hamadryas*) with that of the ruffed lemur and note the differences. In particular, look for normal blade-like lower incisors and a solid bone wall behind the orbit. These are characteristics shared by all of the anthropoids. Also note the larger, more rounded brain case.
6. Examine and be able to distinguish the skulls of the vervet monkey, hamadryas baboon (*Papio hamadryas*), Orangutan (*Pongo pygmaeus*), Gorilla (*Gorilla gorilla*) and Common Chimpanzee (*Pan troglodytes*).

Part 2: Hominid Relationships.

Humans and our extinct ancestors are collectively referred to as **hominids**, reflecting an early tendency to place only humans in the family Hominidae. (Recent practice is to include the other great apes in that same family.)

Anatomical and molecular data place the chimpanzees as the sister group to the hominids and suggest a divergence from a common ancestor about 6 million years ago. In comparison to the apes, humans have a number of derived features that make them quite distinct. These include an upright, bipedal posture and the associated skeletal changes (S-shaped vertebral column, modification of pelvis, femur, feet, etc.), a very large brain (3x larger than chimps), a flat face without a protruding snout, a fully opposable thumb with much greater dexterity, greatly reduced body hair, permanently enlarged breasts, a mostly hidden estrous cycle (no obvious “heat”), and extremely complex social behavior with extended pair bonds, long parental care, language, and complex culture. The adaptive significance of many of these traits is uncertain and controversial.

Exercise 2: Human-Chimpanzee Comparison.

1. Examine the skulls (both male and female) and skeletons of the common chimpanzee (*Pan troglodytes*) and modern human (*Homo sapiens*).
2. Compare the skulls and note any differences. Features to look for include the size of the cranium, jaw projection, shape of tooth row, and location of the foramen magnum.
3. Compare the skeletons and note any differences. Pay particular attention to differences associated with the upright posture of humans, such as the shape of the vertebral column and rib cage, relative lengths of limb bones, and shapes of the pelvis and foot.
4. Fill out the worksheet with your observations of the chimpanzee and human skeletons.

Part 3: Homind Evolution.

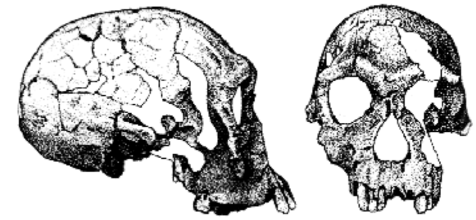
The hominid fossil record has, unsurprisingly, been of considerable interest, and a great deal of effort has been focussed on finding additional hominid specimens. As a result, we know a great deal about our ancestry, although a great many questions remain unanswered. Hominid discoveries have tended to occur in reverse-chronological order of their geological age, with recent forms having been known for much longer than older forms, but here we will present an overview in roughly the sequence in which these species occurred in geological time.

Earliest Putative Hominids — A number of recent finds in northeastern Africa have begun to push the hominid clock further back. Best known is *Ardipithecus ramidus*, recently described from fairly extensive fossil material (but unfortunately not represented in lab). It lived 4.4 million years ago (mya) in woodland. It probably climbed trees, but without the specialized grasping and swinging adaptations of chimpanzees, and when on the ground it likely walked bipedally. Its brain size was comparable to that of a chimpanzee. Despite its age it shows a number of differences from chimpanzees, including small, less sharp canine teeth in males and generalized walking (rather than the specialized knuckle-walking of chimps), suggesting that many of the chimpanzee characteristics are derived and evolved since the divergence from the common ancestor. Several other early species have been named, but their remains are very fragmentary and will not be covered here.

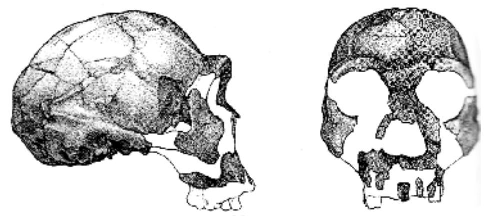
***Australopithecus** africanus*

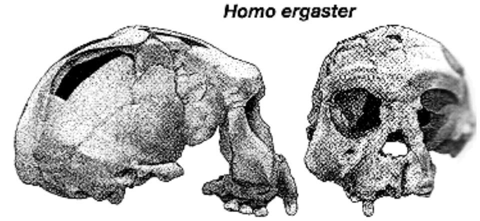
Australopithecine Radiation — Beginning about 4 million years ago, hominids (the australopithecines) began to diversify and spread into other regions of Africa. Two main types co-occurred: the slender, lightly-built *Australopithecus* were relatively small. Although they were bipedal, they were not very efficient walkers and may have spent time in trees. They had relatively small ape-sized brains. A more robust group in the genus *Paranthropus* were larger, more heavily built and had robust skulls and teeth for a more strictly vegetarian diet. The robust lineage eventually went extinct. Several species are known from each genus, and some occurred at the same time and in the same region.

Paranthropus boisei


Homo habilis

Origin of *Homo* — The genus *Homo* is characterized by an increased brain size, decreased jaw and tooth size, and decreased sexual dimorphism. The earliest member of this genus is *H. habilis*, which appeared about 2.4 mya and in many ways was intermediate between *Australopithecus* and later *Homo* species. It is also the earliest hominid to be associated with stone tools. *H. habilis* most likely evolved directly into or gave rise to *H. ergaster*, a slightly younger (1.9 mya), larger-brained species.

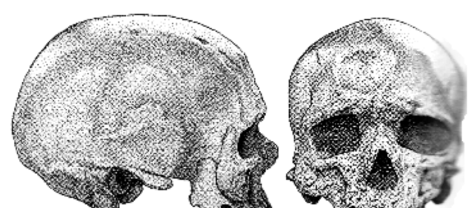

Homo ergaster


Homo erectus

Diversification of *Homo* — The most successful hominid species (in terms of evolutionary longevity) was *Homo erectus*. (It is closely related and similar to an African species, *H. ergaster*.) *H. erectus* was the first hominid to leave Africa about 1.8 mya and spread to Europe and Asia. *H. erectus* (and *H. ergaster*) was similar in size to modern humans, but had a smaller brain (but larger than *H. habilis*), heavy brow ridges, and a more projecting jaw. *H. erectus* went extinct about 300,000 years ago in Asia (and possibly as recently as 50,000 years ago on Java). A closely related dwarf species, *H. floresiensis*, popularly known as the "hobbit," persisted on some Indonesian islands until as recently as 12,000 years ago! (And some claim that the Orang Pendek, a mysterious ape-like creature purportedly sighted in Sumatra, is a relict population of *H. erectus* or *H. floresiensis.*) Meanwhile, in Africa, *H. ergaster* probably gave rise to *H. heidelbergensis*, which in turn gave rise to both *H sapiens* and *H. neanderthalensis*, the latter of which lived in Europe until about 30,000 years ago.

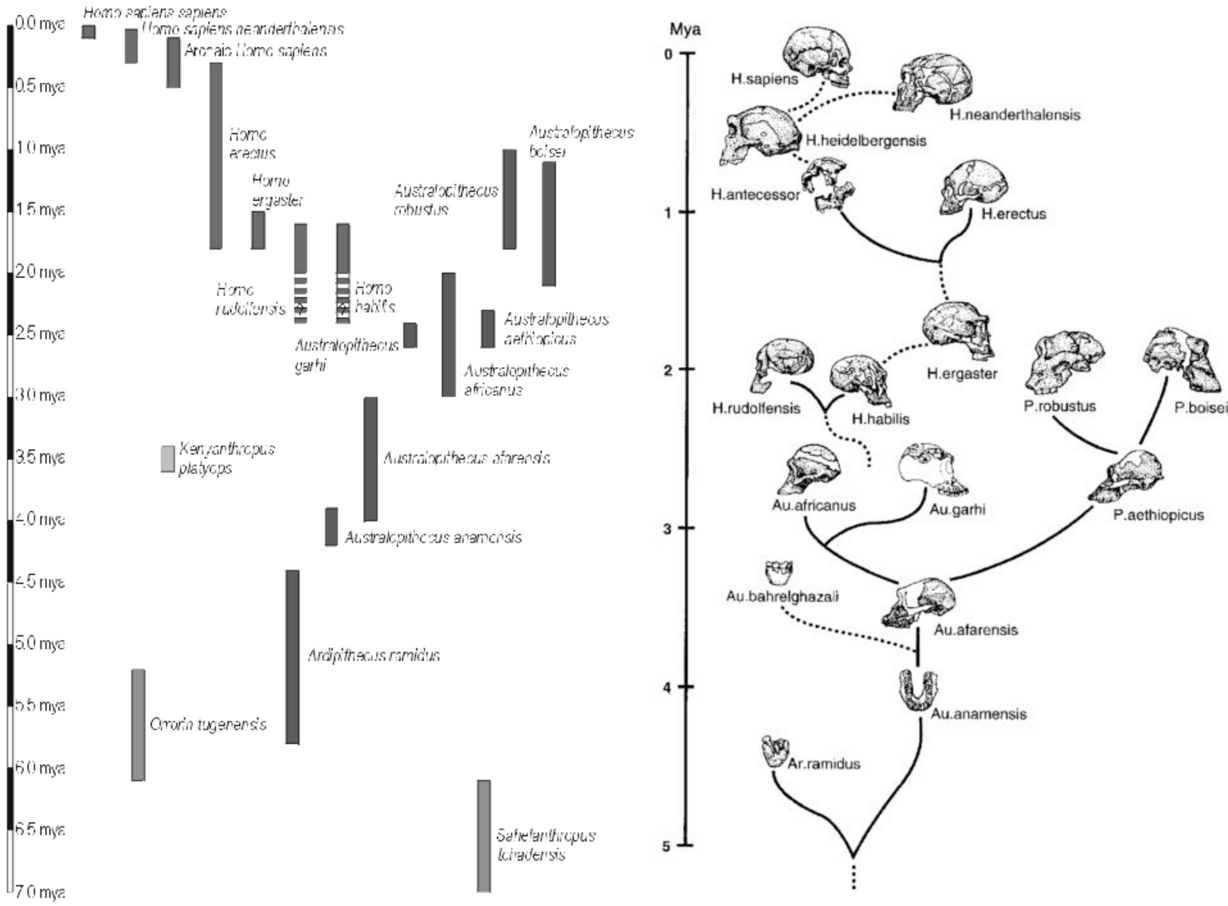

Homo neanderthalensis

Modern Humans — Modern humans, *H. sapiens*, first appeared in Ethiopia about 160,000 years ago and gradually spread from there to the Middle East, Europe, and Asia. As they did so, they appears to have replaced the local hominids (*H. erectus*, *H. neanderthalensis*). Modern humans are about the same size but less robust than their relatives, and lack the heavy brow ridges. They had much more sophisticated behavior, with superior tools, creativity, and art.


Homo sapiens

The timelines and relationships of the hominid species are summarized in Figure 4, below.

Figure 4. *Hominid relationships. Left: the approximate duration of the main hominid species as indicated by the fossil record. Right: the presumed relationships of the major groups of hominids.*



Exercise 3: Fossil Hominids.

1. Examine the skull reproductions of some of the most important and best known fossil hominids.
2. Identify each of these specimens to genus and species.
3. Fill in the table and chart on the worksheet.

Part 4: Hominid Brain Size.

One aspect of hominid biology that has been of particular interest is the evolution of the large human brain. In the 1800s and early 1900s it was thought that the large brain must have evolved first and then later came other human adaptations such as a shorter jaw and upright posture. This all changed with the discovery of small-brained, upright walking Australopithecines in Africa beginning in the 1950s.

Although hominid brains are not preserved directly, their size can be estimated by the volume of the brain case of the skull (similar approaches can be applied to dinosaur brains). Modern techniques include digital reconstructions from CT scans of fossils, but the traditional approach we will use in lab works as well.

Exercise 4: Estimating Hominid Brain Size.

1. Obtain two or three hominid skull reproductions (or a hominid and the chimpanzee skull). Although these skulls are designed for teaching and do not attempt to accurately render the interior spaces, they can still provide a reasonable approximation of volume.

3. Using a funnel, fill the entire brain case by pouring beans (or whatever other material has been made available to you) into the foramen magnum. You should carefully shake your skull to allow the beans to settle.

4. Once you have completely filled your skull, carefully and without spilling, pour the contents into an empty graduated cylinder.

5. Note the level of the material in the cylinder and record your results on the worksheet and on the board or computer.

6. Be sure you have recorded the entire class data before leaving.

Name: ______________________________

Lab 15 Worksheet

Part 1. Primate Diversity

1. Compare the ruffed lemur skull to the vervet monkey and baboon skulls. Fill out the following table, comparing the characteristics indicated.

Trait	Ruffed Lemur	Vervet Monkey	Hamadryas Baboon
Shape of cranium (brain case)			
Relative length of snout			
Post-orbital wall			
Number of upper and lower teeth			
Shape/position of incisors			
Size of cheek teeth			

2. For each of the following primate skulls, identify one or two characteristics that you can used to distinguish them from the other anthropoid species in lab.

Vervet Monkey —

Hamadryas Baboon —

Chimpanzee —

Orangutan —

Gorilla —

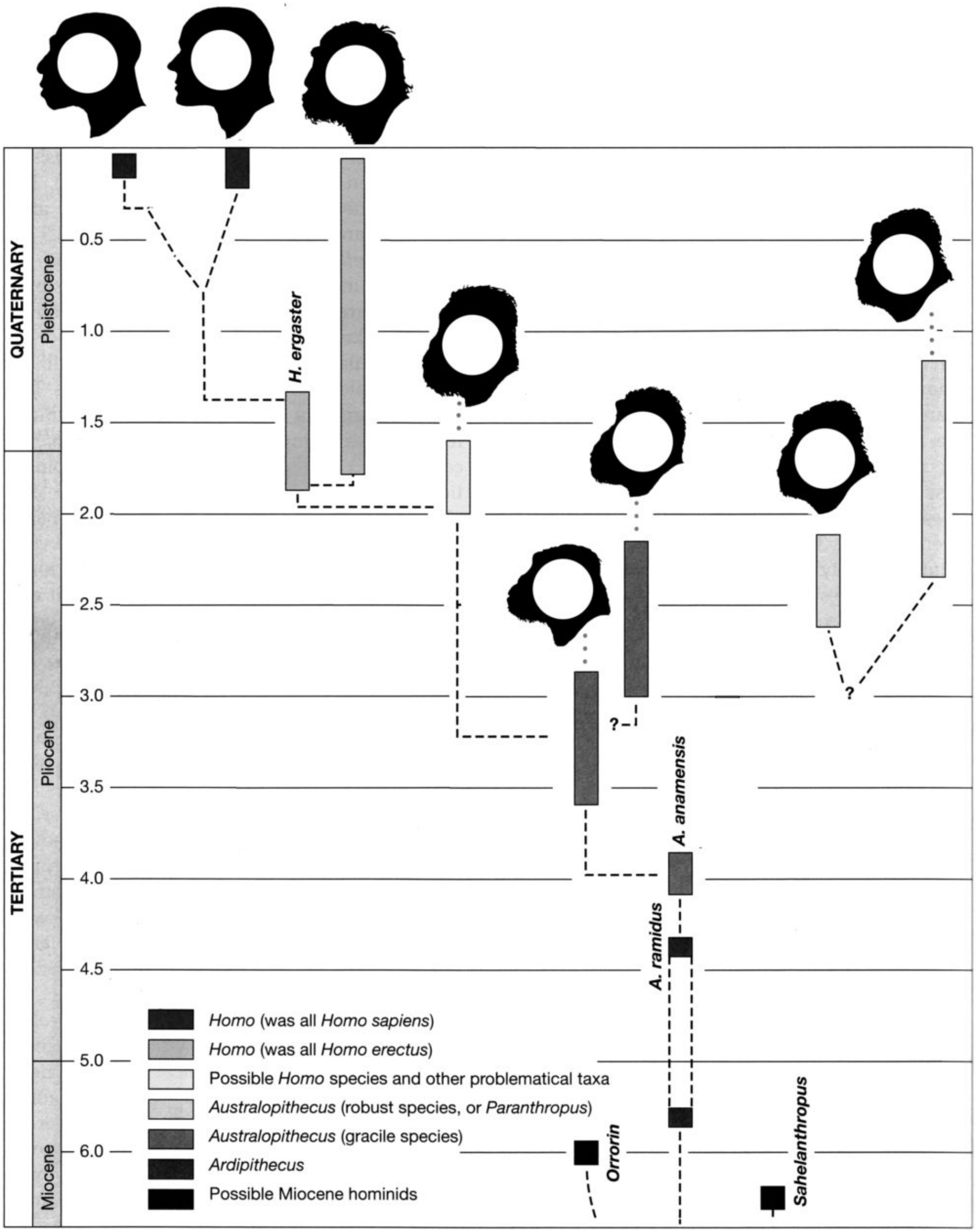
3. Compare the chimpanzee and human skulls and skeletons that are available in lab. Fill out the following table, comparing the characteristics indicated:

Trait	Chimpanzee	Human
Skull:		
Size and shape of cranium		
Jaw projection		
Size of canines		
Shape of cheek teeth rows (parallel sided vs. a curved U shape)		
Orientation of foramen magnum		
Post-cranial skeleton:		
Shape of vertebral column		
Length/shape of rib cage		
Length of humerus vs femur		
Shape of illium (upper portion) of the pelvis		
Shape of phalanges		
Big toe on foot		

4. Examine the replicas of fossil hominids available in the lab. For each, try to identify **derived characteristics** that distinguish it from its closest ancestor (typically the species above it in the table below. For *Australpithecus afarensis*, compare it to that of the chimpanzee skull. Characteristics to look at include the shape and size of the cranium, the size of the mandible, the shape and size of the teeth, the presence of brow ridges or sagittal crests, jaw projection, etc.

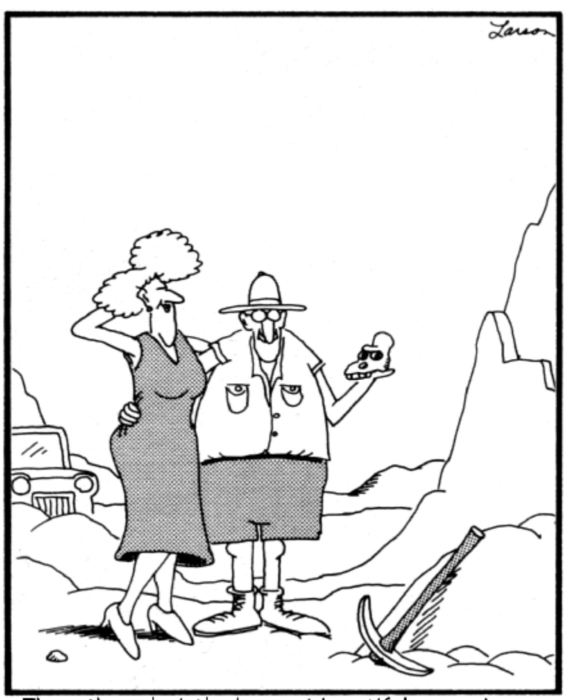
Species	**Derived Characteristics**
1. *Australopithecus afarensis*	(Compare to chimpanzee, *Pan troglodytes*)
2. *Australopithecus africanus*	(Compare to *A. afarensis*)
3. *Paranthropus aethiopicus*	(Compare to *A. africanus*)
4. *Paranthropus boisei*	(Compare to *A. africanus*)
5. *Homo habilis*	(Compare to *A. africanus*)
6. *Homo erectus*	(Compare to *H. habilis*)
7. *Homo neanderthalensis*	(Compare to *H. erectus*)
8. *Homo sapiens*	(Compare to *H. neanderthalensis*)

5. The figure below represents a simplified phylogeny and timeline for hominids (not all species are shown). The time for each species is indicated by the shaded bars. Indicate the position of each of the hominid species you observed in lab by writing in the species number from the previous table (Question 4) inside the head silhouettes.

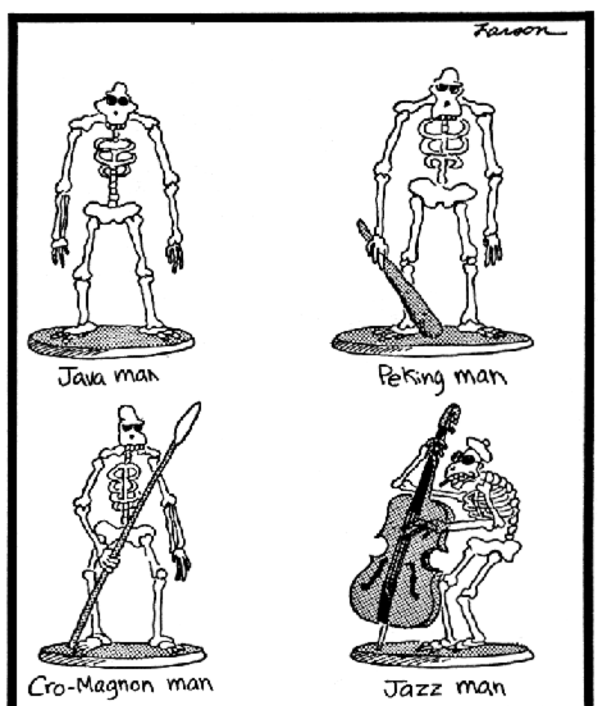


6. Record the cranial capacity (brain size) data from your measurement and from the other students into the table below. If a species brain case was measured more than once, record the average of the measurements instead.

Species	**Age When First Appeared (million years)**	**Mean Cranial Capacity (ml)**
Pan troglodytes	6.0?	
Australopithecus afarensis	3.9	
Australopithecus africanus	3.0	
Homo habilis	1.9	
Homo erectus	1.8	
Homo neanderthalensis	0.3	
Homo sapiens "Cro Magnon Man"	0.16	
Homo sapiens Modern	0	

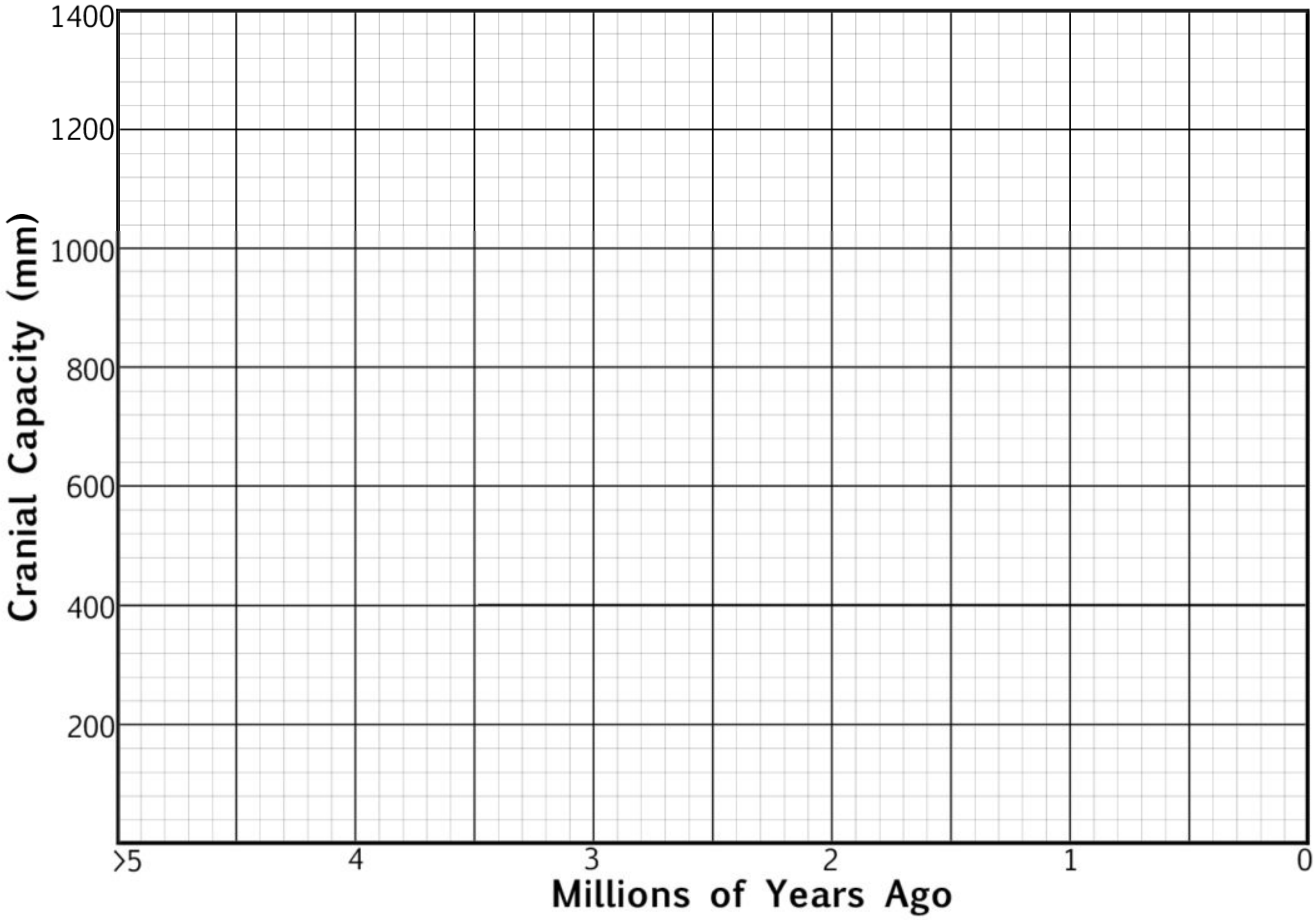


The anthropologist's dream: A beautiful woman in one hand, the fossilized skull a Homo habilus in the other



Hominid Reconstructions

7. Graph the relationship between date of first appearance of a species and its cranial capacity



8. Based on the graph above, how would you describe the overall trend or pattern of brain size evolution in Hominids?

9. Based on the graph above, How does the brain size of early hominids such as *Australopithecus* differ from that of chimpanzees?

10. During what time interval (millions of years ago) did hominid brain size evolve most rapidly?