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Exploring the Submerged New World 2009

Now, Take a Deep Breath

(Adapted from the 2007 Cayman Island Twilight Zone Expedition)

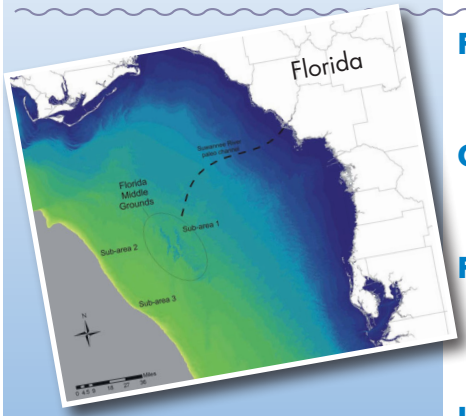

Image captions/credits on Page 2.

lesson plan

Focus

Physics and physiology of SCUBA diving

Grade Level

9-12 (Chemistry/Physics/Biology)

Focus Question

What physiological problems are associated with SCUBA diving, and how can these problems be overcome?

Learning Objectives

- Students will be able to define Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures, and explain their relevance to SCUBA diving.
- Students will be able to discuss the causes of air embolism, decompression sickness, nitrogen narcosis, and oxygen toxicity in SCUBA divers.
- Students will be able to explain the advantages of gas mixtures such as Nitrox and Trimix and closed-circuit rebreather systems.

Materials

- ❑ Copies of *SCUBA for Archaeology Inquiry Guide*, one copy for each student or student group

Audio-Visual Materials

- ❑ None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Classroom style or groups of 2-4 students

Maximum Number of Students

32

Key Words

Coral Reefs
SCUBA
Henry's Law

Boyle's Law
Dalton's Law of Partial Pressures
Air embolism
Decompression sickness
Nitrogen narcosis
Oxygen toxicity
Nitrox
Trimix

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

Many theories have been suggested to describe the origin of the first humans to inhabit North and South America. Current evidence (Goebel, *et al.*, 2008) indicates that these humans migrated from Siberia around 15,000 years ago, crossed a land bridge to the Pacific coast of North America, and continued southward, possibly using boats. Descendants of these migrants spread across what is today the United States, eventually reaching the Atlantic coast. Others continued southward into South America.

Coastal areas inhabited by early Americans are difficult to explore because the coastlines of 15,000 years ago are now under more than 300 feet of water! As the last ice age drew to a close, melting ice sheets caused a rapid rise in sea level just as the first Americans were entering the New World. Drowned settlements may contain well-preserved artifacts that can provide important new information about how the first Americans lived and when they arrived at various locations in North and South America. The eastern Gulf of Mexico in the vicinity of the Ocala Uplift Zone (Florida) is particularly promising as a potential location for drowned coastal settlements because:

- There are numerous onshore archaeological sites along the same zone that are more than 13,000 years old;
- Clusters of similar sites have been identified along drowned shorelines in the northern Gulf of Mexico;
- Rivers that discharge into this part of the Gulf do not carry large quantities of sediment, so sites should not be deeply buried;
- The coastal shelf is gently sloped which would reduce the impact of waves and storms; and
- Rapid sea level rise would have reduced the impact of waves as coastal settlements were inundated.

In 2008, NOAA's Office of Ocean Exploration and Research sponsored an expedition to the northeastern Gulf of Mexico to search for evidence of coastal settlements that might have been inhabited by the first

Images from Page 1 top to bottom:
The eastern Gulf of Mexico showing the three sub-areas examined in 2008, the Florida Middle Grounds, and the Suwanee River paleo channel.
http://oceanexplorer.noaa.gov/explorations/09newworld/background/plan/media/fmg_surveyareas.html

During the Late Pleistocene Florida's shoreline extended much farther offshore than the present coast. The Florida Middle Grounds were part of the exposed coastal margin.
http://oceanexplorer.noaa.gov/explorations/09newworld/background/climatechange/media/pleistocene.html

Map of the Bering land bridge during the late Wisconsin glaciation, when global sea level dropped to about 120 meters or more below its present position.
http://oceanexplorer.noaa.gov/explorations/09newworld/background/occupation/media/beringia_late_wisconsin.html

This image portrays a more accurate reconstruction of Ice Age human behavior with a focus on small familial groups and the processing and use of plants as opposed to athletically fit young men attacking large, dangerous animals.
http://oceanexplorer.noaa.gov/explorations/09newworld/background/beliefs/media/correctpaleobehavior.html

All images courtesy NOAA.

Americans. This expedition focused on ancient river channels in the vicinity of the Florida Middle Grounds, which are now several hundred feet below the Gulf's surface. Major accomplishments included:

- Locating and high resolution mapping of a large, essentially intact, and infilled ancient river channel several kilometers long, east of the Florida Middle Grounds;
- Identifying additional stream and river channels, some with clearly visible deposits along the banks;
- Locating and identifying more than 100 sinkhole features filled with material in stratified layers that may contain human artifacts as well as plant and animal material from early American times; and
- Mapping nearly 10 square kilometers of intact, shallow-water, near-shore sand ripples/ridges adjacent to an area that would have been Florida's shoreline when sea level was at it lowest point during the last glacial period.

The latter achievement is particularly important because it shows that the oldest shoreline is extraordinarily well preserved. Most interesting, though, are the infilled sinkholes with multiple layers of distinct strata. A sinkhole is a hole in the ground that is formed when the roof of an underground cave collapse. In Florida, underground caves are formed by acidic rainwater that dissolves limestone rock, which is the major type of rock that underlies the land surface. When the roof of a cave becomes unstable, it collapses to form a sinkhole.

When the first humans arrived in Florida, sea level was much lower and there was more than twice as much dry land as exists today. The climate was considerably drier, and water was scarce. Not surprisingly, early American settlements that have been discovered in the state are almost always associated with a reliable water supply such as rivers and springs. These areas would also have been attractive to animals, increasing the likelihood that human hunters would be able to find food. So it follows that some of the most artifact-rich paleoamerican sites are located near sinkholes. This association means that archaeologists looking for early American settlements along drowned shorelines of Florida can look for sinkholes as indicators of promising sites. The sinkholes discovered by the Northeastern Gulf of Mexico 2008 expedition are a potential treasure trove of new information about the late Pleistocene landscape and environment, and the humans who lived there.

The Exploring the Submerged New World Expedition returned to further explore this area in 2009 using remote sensing to cover large areas of the ocean floor, and SCUBA diving to directly observe much smaller areas. Diving to depths as much as 130 feet, archaeologists were able to stand on a landscape that humans have not visited for over 10,000 years. This lesson guides student inquiries into the basic principles of physics and physiology that made these visits possible.

Learning Procedure

1. To prepare for this lesson:
   (a) Review introductory essays for the Exploring the Submerged New World 2009 Expedition at http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html; and
   (b) Review questions in the *SCUBA for Archaeology Inquiry Guide*. You may also want to review "SCUBA Diving to Research the Submerged New World: Underwater Archaeology Face to Face," http://oceanexplorer.noaa.gov/explorations/09newworld/logs/jul25/jul25.html.

2. Briefly introduce the Exploring the Submerged New World 2009 Expedition. Highlight the timing of human migration into North and South America, and the fact that these people were hunters who co-existed with mammoths, mastodons, sabre-toothed cats, and giant sloths. Tell students that part of the Exploring the Submerged New World 2009 Expedition involves SCUBA diving, but do not discuss the reasons at this point. Give each student or student group a copy of *SCUBA for Archaeology Inquiry Guide*, and explain that their assignment is to investigate some of the problems that confront diver archaeologists, and how these problems can be managed.

3. Lead a discussion of students' answers to questions on the *Inquiry Guide*. The following points should be included:
   (1) Students should have discovered that Florida's climate in the late Pleistocene was much drier than it is today, and that sea level was much lower. Fresh water and food would have been high priorities for early humans in the area, and springs, lakes, and sinkholes could have provided both. Many early settlements would be underwater today because sea level is higher, so searching and exploring these sites requires SCUBA techniques, remote sensing, or underwater robots.

   (2) Henry's Law states that the mass of a gas which dissolves in a volume of liquid is proportional to the pressure of the gas.

   Boyle's Law states that the product of the volume and pressure of a gas held at a constant temperature is equal to a constant ($PV = k$). So, if the pressure of the gas doubles, the volume will be decreased by half; and if the volume of a gas doubles, the pressure must decrease by half.

   Dalton's Law of Partial Pressures states that the pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by the gases individually.

(3) Henry's Law tells divers that breathing gas at higher-than-normal pressures will cause their bodies to absorb more gases than are absorbed at lower pressures. Absorbed gases can cause decompression sickness as well as toxic effects, and divers must follow certain procedures to avoid these problems. A diver who descends to a depth of 100 feet has a greater risk of decompression illness than one who dives only 30 feet deep. Since the shallow diver has absorbed less gas, it is less likely to come out of solution in the body. Note that the amount of gas dissolved in body tissues also depends upon how long a diver remains at a given depth. If a diver remained at 30 feet for several hours, dissolved gases might be a problem.

Boyle's Law is important to a diver because it means that if a diver fills his lungs with air while he is underwater, that air will expand in his lungs as he rises to the surface. If he holds his breath, the expanding air can rupture his lungs. So the golden rule of diving is: Never hold your breath!

Dalton's Law of Partial Pressures allows a diver to predict how much of a specific gas will dissolve in her blood at a given depth. This is important, because some gases become toxic or cause mental impairment when their partial pressure in the blood rises above a particular level.

(4) An air embolism is a bubble of air or other gas that is large enough to wholly or partially block a blood vessel. Air embolism in a diver might result from breath-holding as the diver rises from deep to shallow water, since the air in the diver's lungs would expand as the external pressure decreased. If the air expanded enough, it could rupture the lungs and allow bubbles of air to enter the bloodstream.

(5) Decompression sickness results from bubbles forming in a diver's blood. If the bubbles are of sufficient size, they may block important blood vessels, causing pain, paralysis, or death. Such bubbles can form when a diver ascends so rapidly that dissolved gases do not have time to diffuse out of the blood, similar to the result of rapidly opening a can of carbonated soda. Decompression sickness in divers usually involves bubbles of nitrogen. Oxygen in air does not form such bubbles because much of the oxygen dissolved in a diver's blood is quickly bound by hemoglobin, and normal metabolism further reduces blood oxygen concentration.

(6) Nitrogen narcosis is an effect similar to alcohol intoxication that may occur when the partial pressure of nitrogen in a diver's blood rises above about 3 atmospheres (corresponding to a depth of about 30 m). The severity of the impairment depends upon

individual susceptibility as well as environmental conditions (temperature, time of day, etc.).

(7) Oxygen may become toxic at partial pressures above 1.4 atmospheres, causing convulsions. Individual thresholds vary widely and depend upon degree of exertion as well as environmental conditions.

(8) At the surface, pure oxygen has a partial pressure of 1.0 atmosphere. Since pressure increases by 1.0 atm for every 10 m (or 33 ft) of depth, the 1.4 atm threshold for oxygen toxicity would be reached at a depth of 4 m, or about 13 ft. Note that pure oxygen is sometimes used at depths of 6 m or less to shorten decompression times. This is possible because resting raises the threshold at which toxicity appears.

(9) Air contains about 21% oxygen, so the partial pressure of oxygen in the blood is about 0.21 atmosphere at the surface. At 10 m, the partial pressure would be 0.42 atm, increasing by 1 atm for every 10 m of depth. So the threshold of 1.4 atm would be reached at a depth of 60 m or 196 ft.

(10) Nitrox mixtures contain nitrogen and oxygen but with less nitrogen and more oxygen than ordinary air. Nitrox mixtures can be used at moderate depths without risking oxygen toxicity, and allow divers to greatly decrease the time needed for decompression.

Trimix is a breathing gas mixture composed of helium, oxygen, and a third gas which is usually nitrogen. The advantage of trimix is that the concentrations of oxygen and nitrogen are reduced so that divers may descend to greater depths without risking oxygen toxicity or nitrogen narcosis. In addition, the density of the breathing mixture is reduced compared to air, which makes it easier to breathe at higher pressures.

(11) Closed-circuit rebreather systems recapture oxygen in exhaled breathing gas, allowing a diver to carry much less breathing gas. In addition, modern closed-circuit rebreathers constantly monitor oxygen levels in the breathing mixture and are able to adjust the oxygen concentration to a level that is optimum for the divers' depth. The result is much shorter decompression times and much less risk of oxygen toxicity.

The BRIDGE Connection

http://www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, scroll over "Ocean Science Topics," then "Human Activities," then click on "Recreation" for links to resources about SCUBA diving.

The "Me" Connection

Have students write a brief essay in which they imagine themselves to be underwater archaeologists, and explain their personal preference for exploration using SCUBA techniques, manned submersibles, remote sensing instruments, or underwater robots.

Connections to Other Subjects

English/Language Arts, Geography, Mathematics

Evaluation

Inquiry guides and discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html for more about the Submerged New World 2009 Expedition.

2. Visit the Newton's Apple Teacher Guide for SCUBA diving at http://www.newtonsapple.tv/TeacherGuide.php?id=1673.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(The following Lesson Plans are targeted toward grades 9-12 unless otherwise noted)

Do You Have a Sinking Feeling?
http://oceanexplorer.noaa.gov/explorations/03portland/background/edu/media/portlandsinking.pdf
(9 pages, 764k) (from the 2003 Steamship Portland Expedition)

Focus: Marine Archaeology (Earth Science/Mathematics)

In this activity, students plot the position of a vessel given two bearings on appropriate landmarks, draw inferences about a shipwreck given information on the location and characteristics of artifacts from the wreck, and explain how the debris field associated with a shipwreck gives clues about the circumstances of the sinking ship.

My Wet Robot
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/wet_robot.pdf
(7 pages, 260 kb) (from the Project PHAEDRA 2006 Expedition)

Focus: Underwater Robotic Vehicles (Physical Science)

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations,

identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

What's Eating Titanic?
http://oceanexplorer.noaa.gov/explorations/04titanic/edu/media/Titanic04.Rusticles.pdf
(5 pages, 408k) (from the RMS *Titanic* 2004 Expedition)

Focus: Biodeterioration processes (Physical Science/Biological Science)

In this activity, students will be able to describe three processes that contribute to the deterioration of the *Titanic*, and define and describe rusticles, explaining their contribution to biodeterioration. Students will also be able to explain how processes that oxidize iron in the *Titanic's* hull differ from iron oxidation processes in shallow water.

This Old Ship
http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/old_ship.pdf
(9 pages, 272 kb) (from the Project PHAEDRA 2006 Expedition)

Focus: Ancient and Prehistoric Shipwrecks (Earth Science/Social Studies) (Grades 7-8)

In this activity, students will be able to describe at least three types of artifacts that are typically recovered from ancient shipwrecks, explain the types of information that may be obtained from at least three types of artifacts that are typically recovered from ancient shipwrecks, and compare and contrast, in general terms, technological features of Neolithic, Bronze Age, Hellenistic, and Byzantine period ships.

The Robot Archaeologist
http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/robot.pdf
(17 pages, 518k) (from the AUVfest 2008 expedition)

Focus: Marine Archaeology/Marine Navigation (Earth Science/Mathematics)

In this activity, students will design an archaeological survey strategy for an autonomous underwater vehicle (AUV); calculate expected position of the AUV based on speed and direction of travel; and calculate course correction required to compensate for the set and drift of currents.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – NOAA's Ocean Explorer Web site

http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html – Web site for the Submerged New World 2009 Expedition

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://www.dep.state.fl.us/geology/geologictopics/sinkhole.htm – Web page on Sinkholes from the Florida Department of Environmental Protection

http://centerfirstamericans.org/index.php – Web site for the Center for the Study of the First Americans

http://www.jqjacobs.net/anthro/paleoamericans.html – Online article on issues and evidence relating to peopling of the New World

http://www.nps.gov/history/aad/eam/index.htm – National Park Service Archaeology and Ethnography Program's Web site, The Earliest Americans

Goebel, T., M. R. Waters, and D. H. O'Rourke. 2008. The Late Pleistocene Dispersal of Modern Humans in the Americas. Science 319:1497-1502.

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure and properties of matter
- Chemical reactions

Content Standard C: Life Science

- The cell

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
Fundamental Concept a. The ocean affects every human life. It supplies fresh water (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.
Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
Fundamental Concept c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.
Fundamental Concept d. Much of the world's population lives in coastal areas.

Essential Principle 7.
The ocean is largely unexplored.
Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and

unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

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Please send your comments to:
oceanexeducation@noaa.gov

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Now, Take a Breath
SCUBA for Archaeology Inquiry Guide

1. Where do you think archaeologists should look for settlements of the first humans in Florida? Why? What technologies might be used to explore these sites? Here are some hints:
   - What was Florida's climate in the late Pleistocene?
   - Why is Florida sometimes nicknamed the sinkhole state?
   - What has happened to sea level since the late Pleistocene?

2. What are Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures?

3. How are these laws relevant to SCUBA diving?

Now, Take a Breath
SCUBA for Archaeology Inquiry Guide – 2

4. What is an air embolism, and how might this happen to a SCUBA diver?

5. What is decompression sickness? Why doesn't oxygen in air cause decompression sickness?

6. What is nitrogen narcosis?

7. At what partial pressure does oxygen become toxic?

Now, Take a Breath

SCUBA for Archaeology Inquiry Guide – 3

8. What is the maximum depth for a diver breathing pure oxygen without risking oxygen toxicity?

9. What is the maximum depth for a diver breathing normal air without risking oxygen toxicity?

10. What are the advantages of gas mixtures such as Nitrox and Trimix?

11. What are the advantages of closed-circuit rebreather systems?