Teacher Resource

National Park Service
U.S. Department of the Interior

Fossil Butte National Monument
Kemmerer, Wyoming

A Carbon Cycle That Rocks

Life Skills:
• Thinking and Reasoning
• Communication

Time Frame:
Two class periods for the activities. Additional time required for extensions and assessments.

Group Size:
Teams of 2-5 students

Teacher's Note—Words that appear in bold print in the text of this document are defined in a supplemental glossary (Pages 15-17).

Summary:
The activities described in *A Carbon Cycle That Rocks* explain elements of the rock cycle by demonstrating the **chemical weathering** and **precipitation** of **carbonate rocks**. The **biogeochemical cycle** of carbon and its pathways in the **atmosphere**, **biosphere**, **hydrosphere** and **lithosphere** during **carbonate sedimentation** and **weathering** will also be investigated (See *Teacher's Note* in the left margin).

National Education Standards:
Content Standard A—Science as Inquiry
- Abilities necessary to do scientific inquiry (5-8/9-12)

Content Standard B—Physical Science
- Properties and changes of properties in matter (5-8)
- Chemical reactions (9-12)

Content Standard D—Earth and Space Science
- Structure of the earth system (5-8)
- Geochemical cycles (9-12)

Main Curriculum Tie:
Idaho

Standard 1—Nature of Science
- Biogeochemical cycles and chemical reactions (9-10.B.1.3.1)

Standard 2—Physical Science
- Conservation of mass and exothermic reactions (8-9.PS.2.5.1)

Standard 4—Earth and Space Systems
- Weathering processes (6.S.4.1.1)

Utah

8th Grade Integrated Science

Standard I—Nature of changes in matter.
- Chemical change (2b)
- Exothermic reaction (3d)
- Reactants and products (4a)

Standard III—Processes of rock and fossil formation
- Rock cycle (2a)
- Weathering (2e)

Earth Systems Science

Standard 5—Atmosphere, biosphere, hydrosphere and lithosphere interactions
- Carbon cycle (1a)
- Pathways (1d)

Wyoming

Science as Inquiry
- Conduct scientific investigations (5-8/9-12)

Concepts and Processes—Earth, Space, and Physical Systems
- Geochemical cycles and chemical reactions (9-12)
- Physical and chemical changes in matter (5-8)

Intended Learning Outcomes:
- Use science process and thinking skills
- Demonstrate understanding of science concepts, principles and systems
- Communicate effectively using scientific language and reasoning

Materials (minimum necessary for each investigative team):

Activity 1

- 3-5 limestone rock chips (pea-sized or smaller)
- 125 ml (4 oz) 10% hydrochloric acid (or vinegar)
- 1-liter beaker (or 1-liter clear plastic cup)

Activity 2

- 26.7 g (2 tbsp) Dow Flakes de-icer (77%-80% calcium chloride)
- 32 grams (2 tbsp) baking soda (sodium bicarbonate)
- 440 ml (15 oz) water (distilled water preferred)
- 125 ml (4 oz) 10% hydrochloric acid (or vinegar)
- 250 ml graduated cylinder (or measuring cup)
- 2-liter beaker (or 2-liter plastic bottle)
- 1-liter beaker (or 1-liter clear plastic cup)
- 250 ml beaker (optional, used in *Step 2*)
- Stirring rod (or magnetic stirrer)
- Funnel
- Watch glass (or wax paper squares)
- Balance (or measuring spoon)
- Thermometer (optional, used in *Extension 1*)
- pH meter/test strips (optional, used in *Extension 1*)
- Coffee filter (or paper towel)

Safety Equipment:

- Laboratory coat (or apron)
- Safety glasses
- Rubber or latex/nitrile gloves

Background For Teachers:

During the late Paleocene and early Eocene, a system of lakes covered much of present day southwestern Wyoming, northwestern Colorado, and eastern Utah (*Figure 1*, reproduced on page 12). Today, what remains of these lakes are the rocks of the Green River **Formation**, which contain a remarkable abundance and diversity of well-preserved fossils.

Fossil Butte National Monument protects a small remnant of one of these lakes, Fossil Lake (*Figure 2*, reproduced on page 13). Its chemically precipitated mud, now turned into ridge-forming limestone and dolomite, is an important factor why over 400 different species of fossil plants and animals are preserved in this paleontological treasure trove. So how did this happen?

The story begins long before the lake formed, in the Late Cretaceous and early Paleogene. A head-on collision between the North American and **Farallon plates** caused the reactivation of a series of **thrust faults** known as the Overthrust Belt. One of those faults, the Absaroka Fault, developed a sizeable depression, called a piggyback basin, in the interior of the fault block that altered local drainage patterns.

A lake began forming in the deepest portion of this basin, known as Fossil Basin, during the early Eocene over 52 million years ago. Initially, the lake was quite shallow and limited in surface area. The lake water contained many dissolved **ions** produced by the weathering of limestone. During this early phase, it was **saturated** with magnesium and calcium that combined with bicarbonate to form **dolomitic** carbonate mud [$(Ca,Mg)CO_3$] by precipitation.

Later, as the lake reached over 60 feet in depth and expanded to more than 930 square miles in surface area, only calcium and bicarbonate were consistently saturated. This resulted in the precipitation of **lime** carbonate mud [$CaCO_3$]. During this second phase, the lake supported its maximum **biodiversity** and conditions became ideal for **fossilization**.

The final phase began as **deposition** outpaced **subsidence** in Fossil Basin.

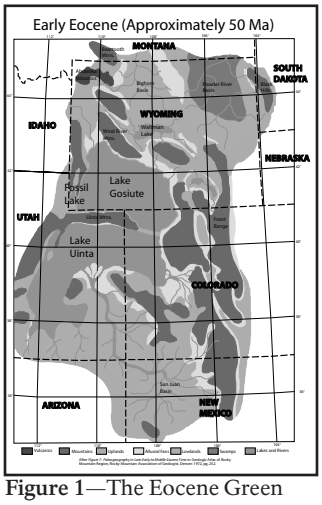


Figure 1—The Eocene Green River lake system (includes Fossil Lake, and lakes Gosiute and Uinta) as it appeared around 50 million years ago.

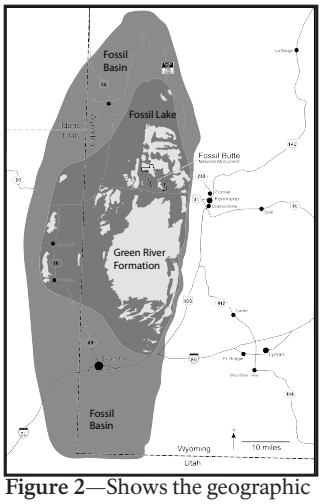


Figure 2—Shows the geographic limits of Fossil Basin (medium gray), the maximum extent of Fossil Lake (dark gray), and the remaining lake sediments known as the Green River Formation (light gray).

Note on Chemical Notation—The abbrevation used for an element is the same as in the Periodic Table. A numerical subscript after the abbreviation indicates the number of atoms of that particular element in a specific compound, if there is no subscript present then it is assumed to be one. The "aq" subscript means the ions within the parentheses are dissolved in an aqueous solution. A superscript plus sign (+) indicates the ion with a positive charge (**cation**). A minus sign (-) superscript indicates an ion with a negtive charge (**anion**). The number after the + or - sign indicates the strength of the charge, if no number is present it is assumed to be one. A right-facing arrow (→) means produces or yields, and indicates the direction of a reaction. Compounds to the left of the arrow are the reactants, and its right are the products. An up arrow (↑) refers to the release of a gas, and a down arrow (↓) to the precipitation of a solid. A numeral before a compound, parenthesis, or ion indicates the number of molecules or atoms necessary to balance the chemical equation.

Simultaneously, the lake level fell as **evaporation** exceeded **recharge**. These conditions may have resulted from a combination of factors including a general decrease in tectonic activity, declining rainfall and altered drainage patterns. Once again precipitated dolomitic mud dominated. In addition, **chert** [SiO_2] and **evaporite minerals** like **halite** [NaCl], **gypsum** [$CaSO_4 \cdot 2\ H_2O$] and **trona** [$Na_3(CO_3)(HCO_3) \cdot 2\ H_2O$] were deposited.

Over time, **burial pressure** and mineralized **pore water** cemented the accumulated mud into a 250-foot-thick dolomite-limestone-dolomite rock sandwich called the Green River Formation. Uplift during the remainder of the Cenozoic Era exposed the rocks to chemical and **mechanical weathering**. Today, the formation covers about 40 percent of the original surface area of Fossil Lake.

As mentioned previously, the dolomitic and lime mud deposited in Fossil Lake formed by precipitating directly from lake water saturated in magnesium, calcium and bicarbonate ions. It was also stated that the likely source of these dissolved ions was the decomposition of limestone. So how does this happen?

As rainwater percolated through soil containing decomposing organic matter, the water combined with carbon dioxide gas trapped in the soil creating a weak acid called carbonic acid (1). Below the soil layer, the newly formed carbonic acid moved along joints and cracks in limestone created by mechanical weathering, and reacted chemically with it, a process known as **acid hydrolysis**. This formed an aqueous solution of calcium and bicarbonate ions (2). These dissolved ions were then transported by **groundwater** and streams into Fossil Lake where they became concentrated enough to precipitate lime carbonate mud (3). See *Note on Chemical Notation* in the left margin.

(1) water + carbon dioxide → carbonic acid

H_2O CO_2 H_2CO_3

(2) carbonic acid + limestone → (calcium ion + two bicarbonate ions)$_{aq}$

H_2CO_3 $CaCO_3$ Ca^{+2} $2\ HCO_3^-$

(3) (calcium ion + two bicarbonate ions)$_{aq}$ → lime mud + carbon dioxide + water

Ca^{+2} $2\ HCO_3^-$ $CaCO_3\downarrow$ $CO_2\uparrow$ H_2O

Some of the carbon dioxide produced reaches the atmosphere where it is taken up by photosynthesizing plants to form living tissue. Sunlight evaporates some of the water. Eventually, the plants die and start decomposing, and water vapor in the atmosphere condenses to form clouds. As falling rain seeps into the soil, it combines with the carbon dioxide produced by the decomposing plant matter to form more carbonic acid and the biogeochemical cycle continues (*Figure 3*, reproduced on page 14).

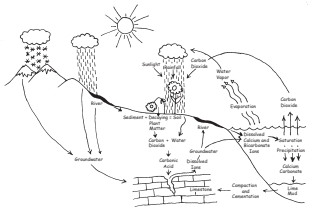


Figure 3—The carbonate rock cycle at Fossil Lake

Instructional Procedures:

Activity 1 (or Teacher Demo)—Fizzy Rocks

Place several pea-sized limestone chips in a 1-liter beaker. Carefully add dilute hydrochloric acid (see *Teacher's Note* in the left margin) to the beaker until the chips are totally submerged. Observe the reaction. Do not splash acid or allow the products of the reaction to overflow the container. Add small amounts of acid as necessary to reinvigorate the reaction.

Teacher's Note—When using dilute hydrochloric acid avoid direct contact with skin, eyes, or clothing. If contact occurs with eyes or skin flush immediately with water. In the case of clothing, remove and rinse with water. The use of protective wear (safety glasses and laboratory coats and gloves) is highly recommended.

Vinegar can be substituted for dilute hydrochloric acid, but the reaction may be less vigorous unless the rock chips are much finer. It also smells bad.

Hold a class discussion. Help students relate what they are observing to things they have experienced before. Use that knowledge to help them speculate about what is happening to the limestone.

Ask leading questions like:

1. What does the reaction between limestone and hydrochloric acid remind you of? [The fizzing of Alka-seltzer, denture cleanser or carbonated beverages like soda pop.]
2. What are those bubbles made of? [Carbon dioxide gas]

3. If we hypothesize that the same gas is released when limestone is dissolved in hydrochloric acid, what does this tell us about the composition of limestone? [It contains atoms of carbon and oxygen that produced the carbon dioxide.]
4. What does the name limestone imply that the stone is made of? [Lime???]

   The lime in limestone is not the fruit, it means calcium oxide. Calcium oxide is a compound composed of one atom each of calcium and oxygen (CaO).

5. If limestone contains only calcium oxide and carbon dioxide, then what is its chemical composition? [One calcium, one carbon and three oxygen atoms]

   Limestone is a carbonate sedimentary rock meaning it contains carbonate. Carbonate is an anion composed of one carbon and three oxygen atoms (CO_3^{-2}). For a rock to be called a limestone it must composed of greater than 50% calcium carbonate ($CaCO_3$). Hydrochloric acid is composed of atoms of hydrogen and chlorine (HCl). The completed reaction is $CaCO_3 + 2\ HCl \rightarrow (Ca^{+2} + 2\ Cl^-)_{aq} + H_2O + CO_2\uparrow$.

6. Why was it necessary to add more acid for the reaction to continue? [The acid was buffered (neutralized) by the decomposing limestone, or there were not enough molecules of acid to dissolve all the limestone.]

Activity 2—Carbonate Soup

Teams will investigate how lime mud formed by precipitation in Fossil Lake during the early Eocene. Students will follow the steps outlined in *A Recipe for Carbonate Soup* (Pages 8-9). For safety reasons teachers may chose to have students skip Step 2 by providing them with a pre-mixed calcium chloride solution (See *Teacher's Note* in the left margin). An optional *Carbonate Soup Laboratory Report* form is provided (Pages 10-11). Examples of completed laboratory forms are included for middle school (Pages 18-19) and high school (Pages 20-21).

Teacher's Note—Dissolving Dow Flakes sidewalk de-icer (77-80% $CaCl_2$) in water is an exothermic reaction producing temperatures in excess of 120°F (~50°C). As a safety precaution it is recommended that teachers prepare the solution in advance. This prevents the potential for burns, and allows the solution to cool to room temperature so that the mixing reaction with the baking soda solution is not so vigorous that it overflows the container.

To prepare the solution add 160 grams (~12 tbsp) of $CaCl_2$ to 180 ml (6 oz) of water. Crushing the flakes to powder in advance will accelerate the dissolving process. If you prefer to have students do this, divide the recipe by six.

As you might suspect, Dow Flakes should not be ingested as saliva will produce the same exothermic reaction and result in burns to the mouth.

Hold a class discussion allowing teams to share their observations, and help them make the connection between the exercise and carbonate rock formation at Fossil Lake as outlined in the *Background for Teachers* section and the student handout, *Fossil Lake: A Carbonate Soup* (Pages 6-7). Use leading questions like:

1. What happened chemically when the baking soda was mixed with water? [The baking soda dissolved. A decomposition reaction occurred that broke the baking soda compound into the sodium and bicarbonate ions that it is composed of.]
2. When you mixed the baking soda solution and calcium chloride solution what did you observe? [The liquid turned a milky white color. When allowed to sit, the liquid cleared and a white precipitate settled to the bottom of the beaker.]
3. What was precipitated? [Calcium carbonate or lime mud.]
4. Why did the mixed solution bubble? [A gas was released by the reaction.]
5. What were those bubbles made of? [Carbon dioxide.]
6. What happened when you added acid to the precipitate? [The precipitate dissolved and a gas was released.]
7. What were those bubbles made of? [Carbon dioxide.]

Key concepts like **chemical reaction**, **ionic** and **covalent bond**, **compound**, **decomposition**, **exothermic**, **replacement**, **reactant**, **product**, **solute**, **solvent**, **aqueous solution**, **phase** and **precipitate** should be introduced into the discussion. Ultimately, the chemical reactions should be derived and compared with those in the *Background For Teachers* section and the student handout, *Fossil Lake: A Carbonate Soup*. This last step is a useful assessment tool.

Extensions:

1. Have students conduct *Exercise 2* for all three reactions: baking soda with water, Dow Flakes with water and the mixing reaction of the aqueous sodium bicarbonate (baking soda) and calcium chloride (Dow Flakes)

solutions using a thermometer, balance and pH meter. This will facilitate an understanding of conservation of mass, exothermic reactions, and other property changes during chemical reactions.

2. Internet research—Have the teams use the internet to find the chemical formula and solubility of baking soda (sodium bicarbonate) and Dow Flakes de-icer (77-80% calcium chloride). Have them find the chemical formula for hydrochloric acid. Have them print a copy of the Material Safety Data Sheet (MSDS) for each of these. This extension is most productive if performed in advance of *Exercise 2* and will aid students in the completion of *Assessment 1*. It also makes them aware of the safety issues associated with handling these chemicals.

Assessment Plans:

1. Have each team prepare a formal report describing the chemical reactions in *Exercise 2* using appropriate scientific language and chemistry notation. A good report should include the following elements:

   Reaction 1—The mixing of baking soda and water resulted in a decomposition reaction that produced an aqueous solution of sodium and bicarbonate ions:

   $$\underset{\text{baking soda}}{NaHCO_3} + \underset{\text{water}}{H_2O} \rightarrow (\underset{\text{sodium}}{Na^+} + \underset{\text{bicarbonate}}{HCO_3^-})_{aq} + \underset{\text{water}}{H_2O}$$

   Reaction 2—The mixing of Dow Flakes de-icer and water resulted in a decomposition reaction that produced an aqueous solution of calcium and chlorine ions:

   $$\underset{\text{Dow Flakes}}{CaCl_2} + \underset{\text{water}}{H_2O} \rightarrow (\underset{\text{calcium}}{Ca^{+2}} + \underset{\text{chlorine}}{2\,Cl^-})_{aq} + \underset{\text{water}}{H_2O}$$

   Reaction 3—The mixing of aqueous solutions of sodium bicarbonate and calcium chloride resulted in a complex reaction including decomposition and replacement that produced an aqueous solution of sodium and chlorine ions, a precipitate of calcium carbonate and carbon dioxide gas:

   $$2\,(\underset{\text{sodium}}{Na^+} + \underset{\text{bicarbonate}}{HCO_3^-})_{aq} + (\underset{\text{calcium}}{Ca^{+2}} + \underset{\text{chlorine}}{2\,Cl^-})_{aq} \rightarrow$$
   $$2\,(\underset{\text{sodium}}{Na^+} + \underset{\text{chlorine}}{Cl^-})_{aq} + \underset{\text{calcium carbonate}}{CaCO_3\downarrow} + \underset{\text{carbon dioxide}}{CO_2\uparrow} + \underset{\text{water}}{H_2O}$$

   Reaction 4—The mixing of the calcium carbonate precipitate with dilute hydrochloric acid resulted in a complex reaction including decomposition and replacement that produced an aqueous solution of calcium and chlorine ions and carbon dioxide gas:

   $$\underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{hydrochloric acid}}{2\,HCl} \rightarrow (\underset{\text{calcium}}{Ca^{+2}} + \underset{\text{chlorine}}{2\,Cl^-})_{aq} + \underset{\text{carbon dioxide}}{CO_2\uparrow} + \underset{\text{water}}{H_2O}$$

2. Have students prepare a graphic organizer illustrating the carbon cycle as it relates to carbonate rocks at Fossil Lake over 50 million years ago (see Figure 3, page 14).
3. Have teams complete *Step 7* in the student handout, *A Recipe for Carbonate Soup*. Based on their previous experience they should be able to explain what reaction has taken place. [The product of *Step 6* is an aqueous solution of calcium and chlorine ions which is equivalent to *Step 2*, or the premixed calcium chloride solution prepared in advance by the teacher. Adding an aqueous solution of sodium and bicarbonate ions to it reproduces the reaction in *Step 3*.]

Fossil Lake: A Carbonate Soup

Fossil Butte National Monument (*Figure A*) in southwestern Wyoming was covered by a lake known as Fossil Lake (*Figure A*) during the early Eocene. Today, the only proof of the lake's existence is the Green River **Formation** (*Figure A*) and the remarkable abundance and diversity of well-preserved fossils it contains.

Over 400 different species of fossil plants and animals including a variety of fish, reptiles, mammals and birds have been discovered here. They tell an important story about an ancient **ecosystem**. Certain species of fossil fish, and reptiles, like the **trionychid turtle**, confirm that Fossil Lake was a freshwater lake.

A look at the modern habitat of the closest living relatives of fossil palm fronds and crocodilians indicate the climate was subtropical. This conclusion is supported by recent research using **leaf margin** and **leaf area analysis** in Fossil Basin (*Figure A*). Results suggest that the **mean annual temperature** was nearly 63°F and **mean annual precipitation** was over 50 inches during the early Eocene. Today, Fossil Butte National Monument is characterized as a high (cold) desert with a mean annual temperature of 42°F and less than 9 inches of mean annual precipitation.

The Green River Formation within Fossil Basin is composed mostly of sedimentary rocks known as **carbonates**, like limestone [$CaCO_3$] and dolomite [$(Ca,Mg)CO_3$]. Unlike many sedimentary rocks, carbonates are not formed simply by **compaction** and **cementation** of **sediment** derived by the **weathering** of older igneous, metamorphic and sedimentary rocks.

Most limestone forms from the cemented remains of coral, plankton and shelled organisms in an ocean environment. Others, like those of the Green River Formation, are formed by chemical **precipitation** of **lime**

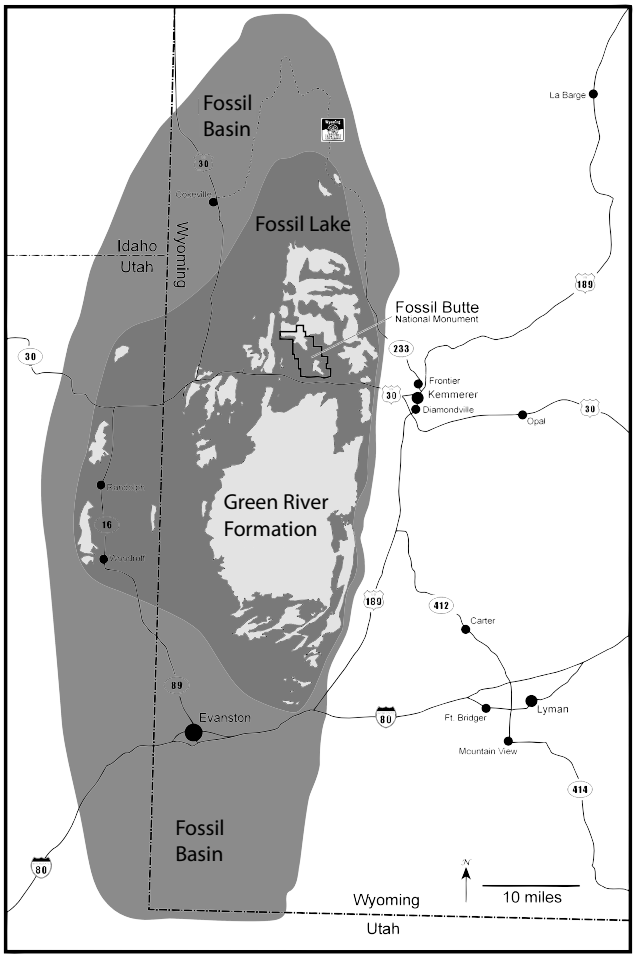


Figure A—Shows Fossil Butte National Monument (outlined in black), Fossil Lake (in dark gray), the Green River Formation (in light gray), and Fossil Basin (in medium gray).

and **dolomitic** mud from a carbonate soup of dissolved calcium (Ca^{+2}), magnesium (Mg^{+2}) and bicarbonate (HCO_3^-) **ions**. So how did this happen?

As rainwater moved through the soil it combined with carbon dioxide gas from decomposing organic matter creating a weak acid called carbonic acid.

$$\text{water} + \text{carbon dioxide} \rightarrow \text{carbonic acid}$$
$$H_2O \qquad CO_2 \qquad H_2CO_3$$

Below the soil layer, the carbonic acid traveled along joints and cracks in limestone created by **mechanical weathering** and chemically attacked it, a process known as **acid hydrolysis**. This formed an **aqueous**

solution of calcium and bicarbonate ions.

carbonic acid + limestone →
H_2CO_3 $CaCO_3$
(calcium ion + two bicarbonate ions)$_{aq}$
Ca^{+2} $2\ HCO_3^-$

These dissolved ions were transported by groundwater and streams into Fossil Lake where they became concentrated enough to **precipitate** lime carbonate mud.

(calcium ion + two bicarbonate ions)$_{aq}$ →
Ca^{+2} $2\ HCO_3^-$
lime mud + carbon dioxide + water
$CaCO_3\downarrow$ $CO_2\uparrow$ H_2O

Some of the carbon dioxide produced is released to the **atmosphere** where it is taken up by photosynthesizing plants to form living tissue, and a portion of the water is **evaporated** by sunlight. Eventually, the plants die and start to decompose and water vapor in the atmosphere condenses to form clouds. As falling rain seeps into the soil, it combines with the carbon dioxide produced by the decomposing plant matter to form more carbonic acid and the **biogeochemical cycle** (Figure B) continues.

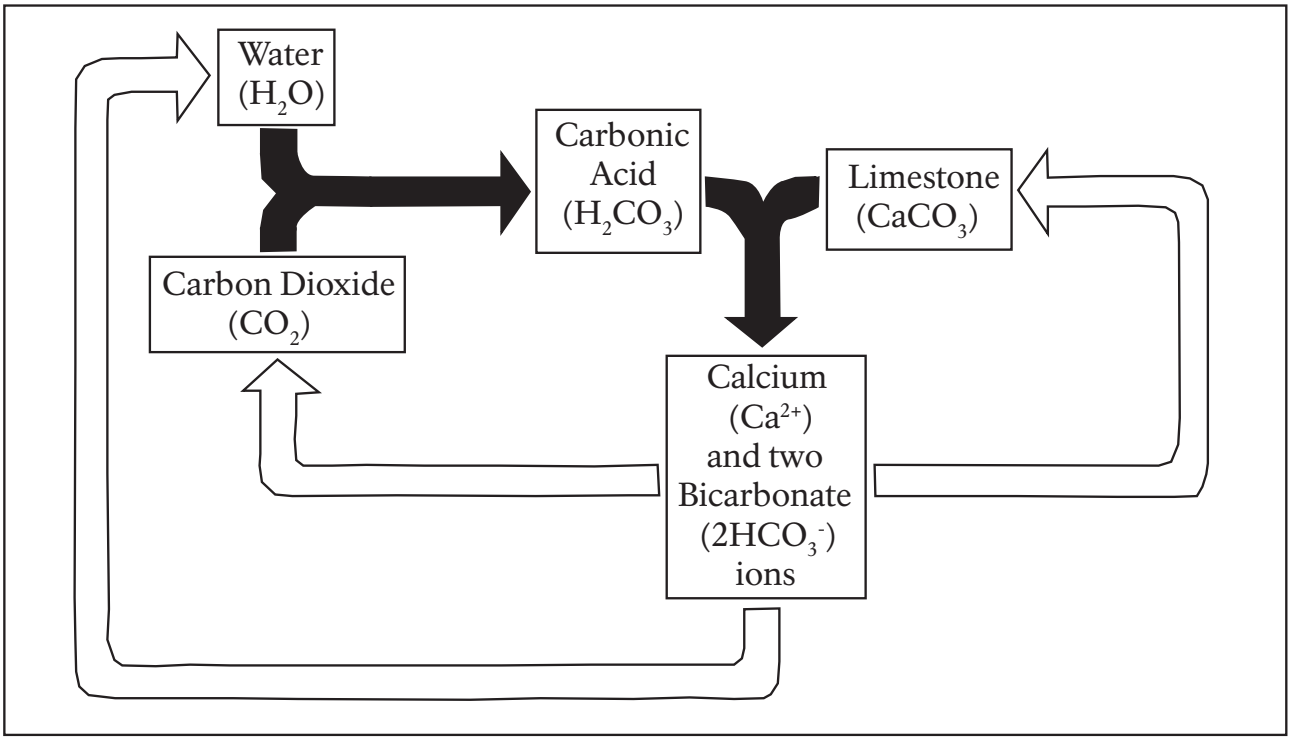


Figure B—The biogeochemical cycle for carbonate rocks at Fossil Lake

A Recipe for Carbonate Soup

Ingredients
2 tbsp (32 g) of baking soda (sodium bicarbonate)
2 tbsp (26.7 g) of Dow Flakes (calcium chloride) or 30 ml of pre-mixed calcium chloride solution
15 oz (440 ml) of water
4 oz (120 ml) of dilute hydrochloric acid or vinegar

Equipment
2-liter beaker
1-liter beaker
250 ml beaker (only necessary for step 2)
250 ml graduated cylinder or measuring cup
balance or tablespoon
watch glass
stirring rod or spoon
funnel
coffee filter or paper towel

Safety Equipment
Rubber or latex/nitrile gloves
Safety glasses
Laboratory coat or apron

Instructions

1. In a 1-liter beaker, combine 2 tbsp (32 g) of baking soda with 14 oz (410 ml) of water. Stir contents until the baking soda is completely dissolved.

   Observe the reaction. Record your observations. Describe the reaction in chemical notation.

2. (Skip this step if your teacher has provided pre-mixed calcium chloride solution.) In a 250 ml beaker, combine 2 tbsp (26.7 g) of Dow Flakes with 1 oz (30ml)of water. Stir contents until completely dissolved. (CAUTION: Avoid direct contact with the solution. You can touch outside of the beaker, but do not attempt to pick up.)

   Observe the reaction. Record your observations. Describe the reaction in chemical notation.

3. Pour the baking soda solution (*Step 1*) into a 2-liter beaker. Slowly add the Dow Flakes solution (*Step 2* or pre-mixed calcium chloride solution provided by the teacher) to the baking soda solution. Stir occasionally to bring reaction to completion. (CAUTION: Do not allow the contents to overflow the container.)

   Observe the reaction. Record your observations.

4. Allow the mixture created in *Step 3* to sit overnight.

   Record your observations. Describe the reaction in chemical notation.

5. Place a coffee filter in a funnel and slowly strain the liquid contents of the 2-liter beaker into a 1-liter beaker. Avoid pouring the **precipitate** into the coffee filter. Carefully remove the coffee filter from the funnel and scrape its contents back into the 2 liter beaker if possible. Dispose of the contents of the 1-liter beaker in a sink with the water running

and the coffee filter in a waste basket.

6. Slowly add 4 oz (120 ml) of dilute hydrochloric acid or vinegar to the contents of the 2-liter beaker. (CAUTION: Do not allow the contents to overflow the container. Avoid direct contact with the acid. If contact occurs, flush affected area immediately with water.) Stir contents until sediment is completely dissolved.

   Observe the reaction. Record your observations. Describe the reaction in chemical notation.

7. (This step may be used as an assessment. Additional baking soda and water is required.) Prepare another baking soda solution as described in step 1. Slowly add this solution to the contents of the 2-liter beaker from step 5. (**CAUTION**: Do not allow the contents to overflow the beaker.)

   Observe the reaction. Record your observations. Describe the reaction in chemical notation.

8. Dispose of the contents of the 2-liter beaker in a sink with the water running.

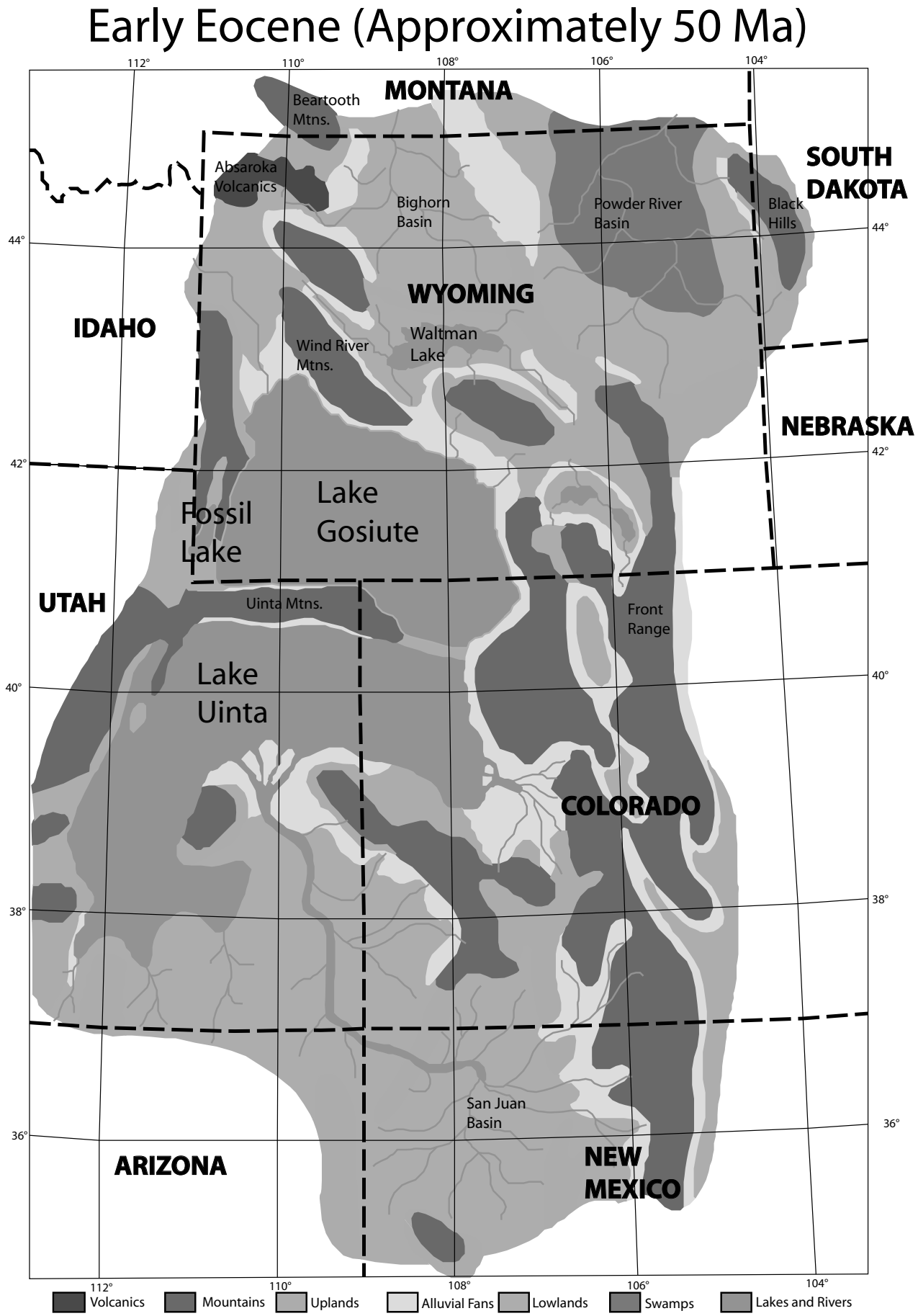
Carbonate Soup Laboratory Report

	Step 1 Mixing baking soda (sodium bicarbonate) and water	Step 2 Mixing Dow Flakes (calcium chloride) and water	Steps 3 and 4 Mixing aqueous sodium bicarbonate and calcium chloride solutions
Reactant(s) and Phase(s)			
Product(s) and Phase			
Reaction Type(s)			
Solute Solvent			
Observations			
Chemical Equation			

	Step 5 Mixing white precipitate and hydrochloric acid	Step 6 Mixing Step 5 and Step 1 solutions
Reactant(s) and Phase(s)		
Product(s) and Phase(s)		
Reaction Type(s)		
Solute Solvent		
Observations		
Chemical Equation		

Date:

Team Members:



After *Figure 7: Paleogeography in Late Early to Middle Eocene Time* in Geologic Atlas of Rocky Mountain Region, Rocky Mountain Association of Geologist, Denver: 1972, pg. 252.

Figure 1—The Eocene Green River lake system (includes Fossil Lake, and lakes Gosiute and Uinta) as it appeared around 50 million years ago.

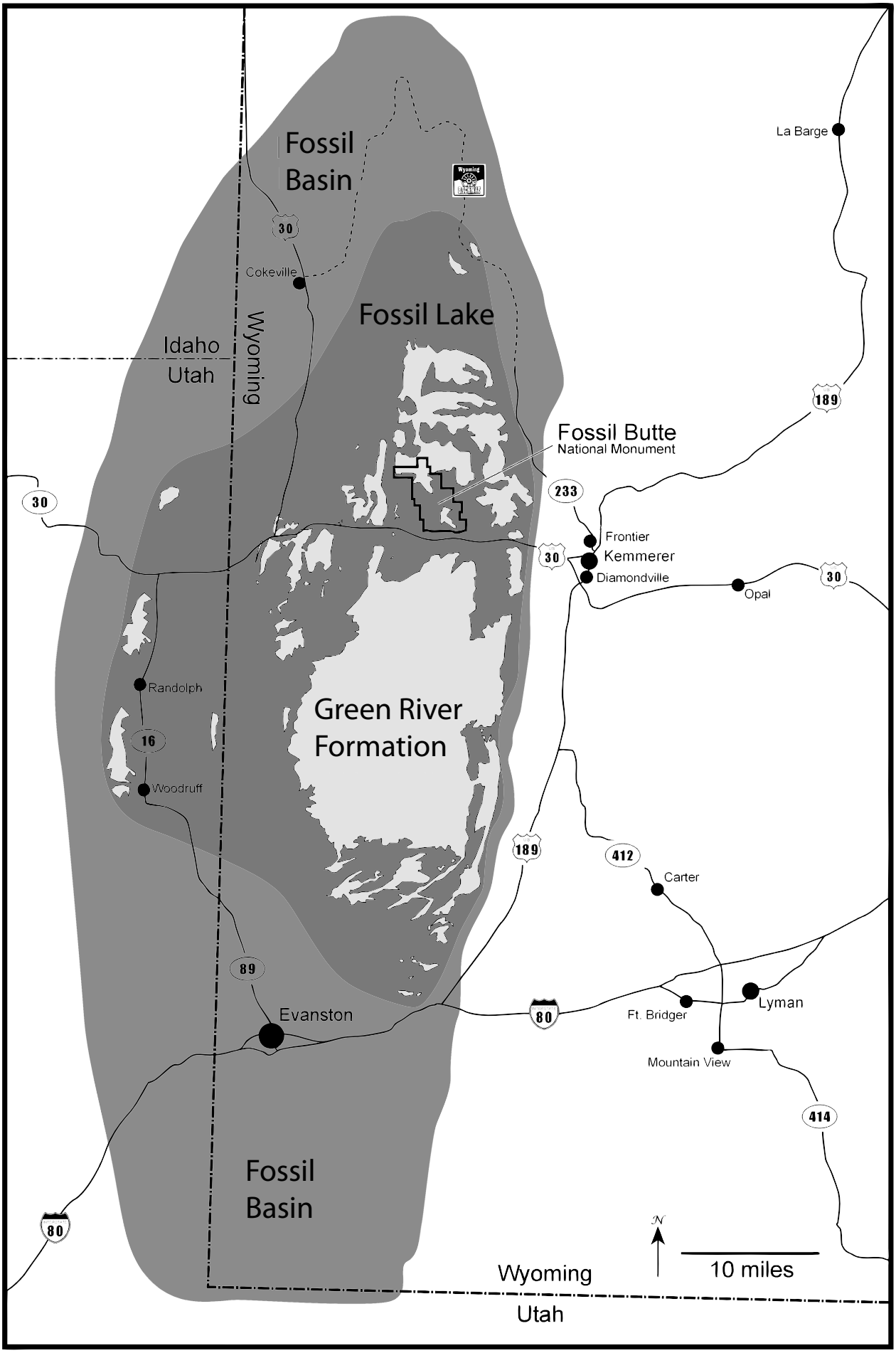


Figure 2—Shows the geographic limits of Fossil Basin (medium gray), the maximum extent of Fossil Lake (dark gray), and the remaining lake sediments now known as the Green River Formation (light gray).

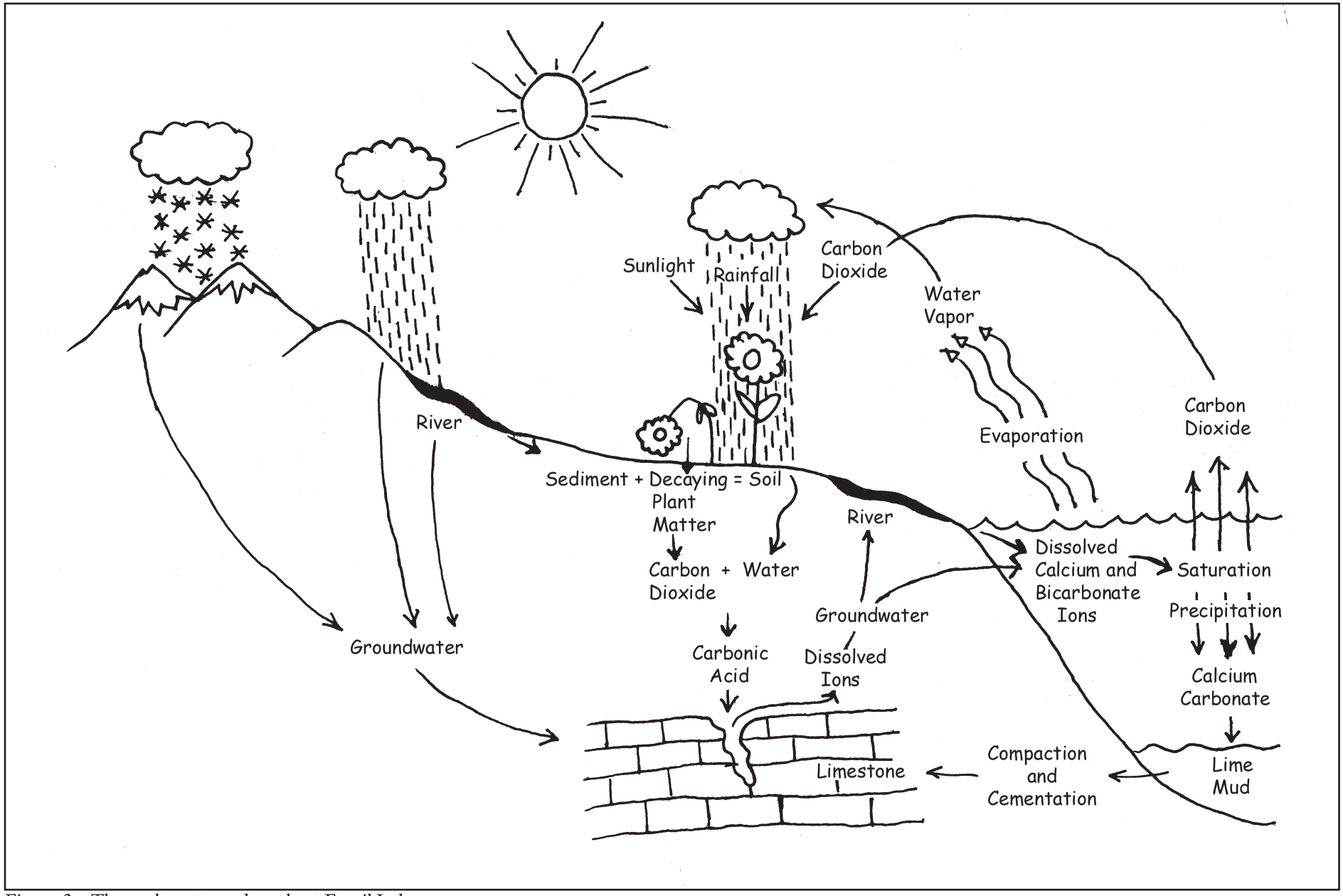


Figure 3—The carbonate rock cycle at Fossil Lake.

Glossary

Acid hydrolysis—a decomposition reaction involving an acid in which hydrogen (H^+) or hydroxyl (OH^-) ions are consumed and an a chemically equivalent amount of an ion is released into a solution.

Anion—an ion with a negative charge, ex. CO_3^-.

Aqueous—made from, with, or by means of water, ex. aqueous solutions.

Atmosphere—the gaseous envelope surrounding the surface of the earth and held in place by gravity; on average it is a mixture of 78% nitrogen, 21% oxygen, 0.9% argon, 0.03% carbon dioxide, and minute quantities of helium, krypton, neon, and xenon.

Biodiversity—the variety of plant and animal species within an environment.

Biogeochemical cycle—the continued exchange and reactions a chemical element passes through due to biological, chemical and geological activity.

Biosphere—all areas of the earth that support or are capable of supporting life.

Burial pressure—the pressure created by the weight of overlying sediment.

Carbonate [mineral]—an inorganic chemical compound containing the carbonate ion (CO_3^{-2}) such as calcite ($CaCO_3$).

Carbonate rock—a sedimentary rock such as limestone or dolomite that is composed of more than 50% carbonate minerals.

Carbon cycle—the continued exchange and reactions of carbon in the atmosphere, biosphere, hydrosphere and lithosphere.

Cation—a ion with a positive charge, ex. Ca^{+2}.

Cementation—the process by which individual grains of sediment become hard rock through the deposition or precipitation of minerals in the space between grains.

Chemical reaction—the process in which substances undergo chemical changes that result in the formation of new substances.

Chemical weathering—the processes that break down rock through chemical change.

Chert—A hard, dense sedimentary rock composed almost entirely of the mineral quartz. It was used by Native Americans to make arrowheads.

Climate—the average weather of a region over a long period of time, particularly as regards temperature and precipitation.

Compaction—a reduction in the volume and thickness of a sediment by loss of pore space in response to the increasing weight of overlying material.

Compound—a substance combining two or more elements in specific proportions, ex. $CaCO_3$, 1Ca:1C:3O.

Covalent bond—a chemical bond formed when two or more atoms share electrons, ex. $2\ H^+ + O^{-2} \rightarrow H_2O$.

Decomposition—a chemical reaction that breaks down compounds into simpler products, ex. $2\ H_2O_2$ (hydrogen peroxide) $\rightarrow 2\ H_2O$ (water) + O_2 (oxygen).

Deposition—the accumulation into layers of loose rock material, chemical precipitates and organic matter by settling of suspended particles.

Dicot—any flowering plant (angiosperm) having two embryonic seed leaves, flower parts in fours or fives, and net-veined leaves including most broad-leaved flowering trees and plants.

Dolomitic—containing a high percentage of dolomite, a calcium magnesium carbonate ($CaMg(CO_3)_2$) mineral.

Ecosystem—a self-sustaining and self-regulating natural community of organisms interacting with one another and their environment.

Evaporation—the process by which a substance passes from a liquid state to a vapor state.

Evaporite mineral—a mineral precipitated from solution by extensive or total evaporation.
Exothermic—refers to the release of energy in the form of heat during a chemical reaction.
Farallon Plate—a tectonic plate that once formed part of the eastern Pacific Ocean floor, but that has been completely overridden by the North American Plate.
Formation—a distinctive, mappable body of layered rock composed of a certain rock type or combination of related types.
Fossilization—all processes involving the burial of a plant, animal, or their traces in sediment and the eventual preservation of all, or part of it.
Groundwater—water that fills the cracks and spaces in buried soil and rock layers.
Gypsum—an evaporite mineral composed of water-bearing calcium sulfate that is used to make plaster of Paris.
Halite—an evaporite mineral composed of sodium chloride commonly called rock salt.
Hydrosphere—consists of all water in any state (liquid, solid, or vapor) found at or below the earth's surface to include oceans, rivers, lakes, groundwater, snow, ice, and glaciers.
Ion—an atom or group of atoms that have become electrically charged.
Ionic bond—a chemical bond formed when two oppositely charged ions are joined in a compound, ex. Na^+ (sodium) + Cl^- (chlorine) → NaCl (sodium chloride, table salt). In the reaction, sodium surrenders its extra (valence) electron to chlorine to complete its outermost electron shell.
Leaf area analysis—a method of determining mean annual precipitation (MAP) based on the surface area of at least 25 different dicot leaf forms.
Leaf margin analysis—a method of determining mean annual temperature (MAT) based on the margin type (entire or toothed) of at least 25 different dicot leaf forms.
Lime—technically, calcium oxide, but commonly misused to indicate a substance composed primarily of calcium carbonate as in lime mud or limestone.
Lithosphere—the solid portion of the earth, composed specifically of the crust and rigid portion of the upper mantle down to an average depth of 100 kilometers.
Mean annual precipitation—yearly precipitation (rainfall, snow, etc.) for a specified location averaged over a long period of time.
Mean annual temperature—average of all temperature readings for a specified location over an entire year averaged over a long period of time.
Mechanical weathering—the process by which rock is physically broken into smaller pieces.
Phase—the physical state (solid, liquid or gas) of a substance.
Plate—a portion of the earth's lithosphere that moves horizontally and adjoins other plates along zones of seismic activity.
Pore water—subsurface water in the voids of rocks and between adjoining grains in sediment.
Precipitate—a solid that forms from solution during a chemical reaction (noun), or the act of forming a solid from the mixing of solutions (verb).
Precipitation—the process by which the mixing of solutions results in the formation of a solid.
Product—a substance formed as the result of a chemical reaction.
Reactant—a substance that enters into a chemical reaction.
Recharge—the process of adding water to the saturated zone by rainfall or runoff.
Replacement—a chemical reaction in which one element replaces another in a compound, ex. 2 Cu_2O (copper oxide) + C (carbon) → 4 Cu (copper metal) + CO_2 (carbon dioxide).
Saturated—containing the maximum amount of solute capable of being dissolved under given conditions.

Sedimentation—the act or process of forming, or accumulating sediment in layers, and the transformation of that sediment into solid rock.

Sediment—solid fragmental material transported and deposited by wind, water, or ice, chemically precipitated from solution, or secreted by organisms, which forms layers of loose unconsolidated material, ex. sand, silt, or mud.

Solubility—a measure of how much solute can dissolve in a given amount of solvent at a particular temperature.

Solute—the part of the solution dissolved by the solvent.

Solution—a well-mixed mixture that contains a solvent and at least one solute.

Solvent—the part of the solution that dissolves the solute.

Subsidence—the sudden sinking or gradual downward settling of the Earth's surface.

Thrust fault—a low angle reverse fault in which the head wall has moved upward relative to the foot wall.

Trionychid turtle—a variety of soft-shelled turtle found only in freshwater ecosystems.

Trona—an evaporite mineral composed of water-bearing sodium carbonate and bicarbonate that is used to make a variety of sodium compounds including soda ash (glass-making) and sodium bicarbonate (baking soda and antacids).

Weathering—the physical break down, or chemical decomposition of solid rock into fragmentary particles and dissolved ions.

The definitions are adapted from several sources including *Random House Webster's College Dictionary (1999), Glossary of Geology (4th Edition, 1997), Dictionary of Geologic Terms (3rd Edition, 1984), Prentice Hall Science Explorer: Chemical Interactions (2007)* and *Prentice Hall Science Explorer: Earth's Changing Surface (2007)*.

Carbonate Soup Laboratory Report

Sample lab report (High School)

	Step 1 Mixing baking soda (sodium bicarbonate) and water	Step 2 Mixing Dow Flakes (calcium chloride) and water	Steps 3 and 4 Mixing aqueous sodium bicarbonate and calcium chloride solutions
Reactant(s) and Phase(s)	$NaHCO_3$ (solid) H_2O (liquid)	$CaCl_2$ (solid) H_2O (liquid)	$(Na^+ + HCO_3^-)_{aq}$ (liquid) $(Ca^{+2} + 2\ Cl^-)_{aq}$ (liquid)
Product(s) and Phase(s)	$(Na^+ + HCO_3^-)_{aq}$ (liquid)	$(Ca^{+2} + 2\ Cl^-)_{aq}$ (liquid)	$(Na^+ + Cl^-)_{aq}$ (liquid) $CaCO_3$ (solid) CO_2 (gas)
Reaction Type(s)	decomposition	decomposition (exothermic)	decomposition replacement
Solute Solvent	$NaHCO_3$ H_2O	$CaCl_2$ H_2O	NaCl H_2O
Observations	$NaHCO_3$ dissolved in H_2O to produce a clear liquid.	$CaCl_2$ dissolved in H_2O to produce a clear liquid. Heat was released.	Mixture turned milky white and bubbled. After sitting, the solution cleared and a white precipitate collected at the bottom.
Chemical Equation	$NaHCO_3 + H_2O \rightarrow$ $(Na^+ + HCO_3^-)_{aq}$	$CaCl_2 + H_2O \rightarrow$ $(Ca^{+2} + 2\ Cl^-)_{aq}$	$2(Na^+ + HCO_3^-)_{aq} + (Ca^{+2} + 2Cl^-)_{aq}$ $\rightarrow 2(Na^- + Cl^-)_{aq} + CaCO_3\downarrow + CO_2\uparrow$

	Step 5 Mixing white precipitate and hydrochloric acid	Step 6 Mixing Step 5 and Step 1 solutions
Reactant(s) and Phase(s)	$CaCO_3$ (solid) HCl (liquid)	$(Ca^{+2} + 2\ Cl^-)_{aq}$ (liquid) $(Na^+ + HCO_3^-)_{aq}$ (liquid)
Product(s) and Phase(s)	$(Ca^{+2} + 2\ Cl^-)_{aq}$ (liquid) CO_2 (gas)	$(Na^+ + Cl^-)_{aq}$ (liquid) $CaCO_3$ (solid) CO_2 (gas)
Reaction Type(s)	decomposition replacement	decomposition replacement
Solute Solvent	$CaCl_2$ H_2O	NaCl H_2O
Observations	$CaCO_3$ dissolved in HCl bubbling vigorously. A clear liquid was produced.	Mixture turned milky white and bubbled. After sitting, the solution cleared and a white precipitate collected at the bottom.
Chemical Equation	$CaCO_3 + 2\ HCl \rightarrow$ $(Ca^{+2} + 2\ Cl^-)_{aq} + CO_2\uparrow$	$2(Na^+ + HCO_3^-)_{aq} + (Ca^{+2} + 2Cl^-)_{aq}$ $\rightarrow 2(Na^- + Cl^-)_{aq} + CaCO_3\downarrow + CO_2\uparrow$

Date:

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Carbonate Soup Laboratory Report

Sample lab report (Middle School)

	Step 1 Mixing baking soda (sodium bicarbonate) and water	Step 2 Mixing Dow Flakes (calcium chloride) and water	Steps 3 and 4 Mixing aqueous sodium bicarbonate and calcium chloride solutions
Reactant(s) and Phase(s)	Baking soda (solid) Water (liquid)	Dow Flakes (solid) Water (liquid)	Aqueous sodium bicarbonate (liquid) an aqueous calcium chloride (liquid)
Product(s) and Phase(s)	Aqueous solution of sodium and bicarbonate ions (liquid)	Aqueous solution of calcium and chloride ions (liquid)	Aqueous solution of sodium chloride (liquid), calcium carbonate (solid) and carbon dioxide (gas)
Reaction Type(s)	decomposition	decomposition (exothermic)	decomposition replacement
Solute Solvent	Sodium bicarbonate Water	Calcium chloride Water	Sodium chloride Water
Observations	Baking soda dissolved in water to produce a clear liquid.	Dow Flakes dissolved in water to produce a clear liquid. Heat was released.	Mixture turned milky white and bubbled. After sitting, the solution cleared and a white precipitate collected at the bottom.
Chemical Equation			

	Step 5 Mixing white precipitate and hydrochloric acid	Step 6 Mixing Step 5 and Step 1 solutions
Reactant(s) and Phase(s)	Calcium carbonate (solid) Hydrochloric acid (liquid)	Aqueous calcium chloride (liquid) and aqueous sodium bicarbonate (liquid)
Product(s) and Phase(s)	Aqueous solution of calcium and chloride ions (liquid) and carbon dioxide (gas)	Aqueous solution of sodium chloride (liquid), calcium carbonate (solid) and carbon dioxide (gas)
Reaction Type(s)	decomposition replacement	decomposition replacement
Solute Solvent	Calcium chloride Water	Sodium chloride Water
Observations	Calcium carbonate dissolved in hydrochloric acid bubbling vigorously. A clear solution was produced.	Mixture turned milky white and bubbled. After sitting, the solution cleared and a white precipitate collected at the bottom.
Chemical Equation		

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