Rock-Density Exercises for Introductory-Level College Courses

Robert Stanley Nelson and Robert Guy Corbett
Department of Geography and Geology
Illinois State University
Normal, Illinois 61790-4400
rsnelso@ilstu.edu
rcorbett@ilstu.edu

ABSTRACT

Students build quantitative and analytical skills as they determine rock density in the laboratory. They measure dimensions, calculate volume, measure mass, and calculate density for eight rock specimens. In the next laboratory meeting, they analyze errors, correct data, and report rock-density values based upon the collective efforts of the class. These data are used again, later in the semester. Compressional velocities of seismic waves are calculated in lecture using the densities for granite and metabasalt. Students calculate the porosity of three sandstones in a later laboratory exercise. Students determine differences in elevation between the continental masses and oceanic basins attributable to densities of continental and oceanic crust in another laboratory exercise. These exercises are effective at building understanding of concepts and quantitative skills, based upon the interpretation of essay-exam scores, laboratory-instructor observations, and student comments.

Keywords: Education – geoscience; education – undergraduate; geophysics – seismology; miscellaneous and mathematical geology.

Introduction

The density of minerals and rocks is generally given minimal time and attention in many introductory geoscience courses but can provide significant opportunities for building the quantitative skills of beginning college students. The topic of density has particular value as a theme that connects the properties of minerals and rocks to later topics such as seismic velocity, isostasy, and porosity.

We offer a general-education course, "Principles of Geology," for about 500 students per semester. Most are non-science majors. The course format involves two one-hour lectures and one two-hour laboratory session each week. Lecture enrollment ranges from about 30 to 240 students. Laboratory sections are under 30 students.

In "Principles of Geology," we devote 13% of our available lab time to the determination of density and consideration of errors in its measurement. In the first of two exercises we have established and piloted, teams of two or three students measure dimensions and weigh blocks of eight different geologic materials. From these measurements, they calculate densities (ρ). We purposely chose rock density rather than specific gravity in order for the students to perform measurements of length and mass, calculate volume, and then calculate density. Each step requires the use of dimensional units and moves the students from more concrete (for example, length, mass) to more abstract concepts (for example, density). Prior to the next laboratory session, the instructor tabulates all data, which are then evaluated during the second lab. In evaluating data, students learn to recognize different types of errors and consider the need for standard procedures, quality control, accuracy, and precision. Students correct the data, decide on an appropriate number of significant figures, and determine an average or representative value of density for each of the eight samples. The data are applied later in the semester to the calculation of first-order isostatic relief (using the densities determined for metabasalt and granite), sandstone porosity (using the densities of quartz and three different sandstones), and seismic velocity.

Determination of Density – The First Laboratory

Prior to their doing the exercises on rock density, the students have had four laboratory sessions on minerals and rocks. They have learned the definition for density and that it has dimensions, the commonly used grams per cubic centimeter (g/cm^3).

Specimens of granite, gneiss, metabasalt, slate, limestone, three different sandstones, and quartz were selected because they have a variety of textures and mineral compositions. Students, working in pairs, measure dimensions of slabbed specimens that have been cut using a rock saw to provide approximately rectangular prisms from one to three centimeters on a side. The specimens are of different volume, but each has nearly rectangular surfaces. As an added challenge, students are provided with some specimens that have a chipped corner.

We provide a choice of devices for measurement of length and for mass. Students may use a ruler, tape measure, dial calipers, or calipers with a vernier scale. They also have a choice of determining mass using a standard model or dialogram model triple-beam balance or a top-loading electronic balance. No hints are given as to what are the best choices for accuracy (for example, calipers with vernier scale, electronic top-loading balance). Students generally choose the most familiar and least discriminating devices – a ruler and a triple beam balance. Very few students have had any prior experience with the other devices. Almost all students attempting to use the vernier scale on calipers experience difficulties.

For a regular rectangular prism, the students take four measurements of length (l), width (w), and height

2.595	2.8	2.88
2.61	2.83	2.89
2.7	2.84	2.89
2.75	2.86	2.89
2.77	2.86	2.915
mean	2.80	
s.d.	0.103	
Published values	2.704-2.851	

Table 1. Density values in g/cm^3 for metabasalt, as reported by the Honors section of Fall, 1999 for the second laboratory. Values are ordered low to high. Published value is from Daly and others, 1966.

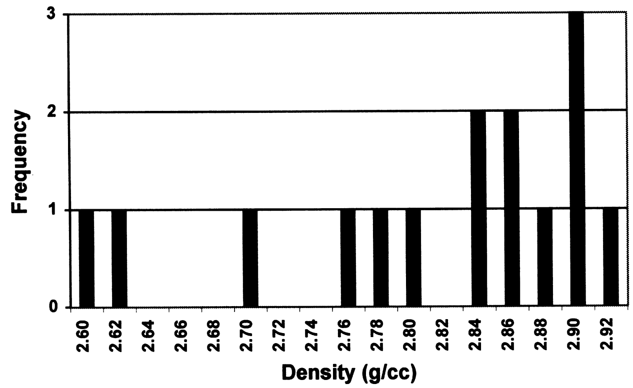

Figure 1. Histogram of density values in g/cm^3 for metabasalt from Table 1.

(h). The twelve measurements are taken through the center of each face (two measurements per face and twelve measurements in total). This approach compensates for the prism faces not being perfectly cut with mutually perpendicular faces. After averaging values for length, width, and height, students calculate volume.

For a specimen with a chipped corner the procedure is modified. Students measure length, width, and height along surfaces not affected by the missing corner as described above, and calculate the original volume (vo). They also measure the length (lm), width (wm), and height (hm) along edges where the corner is missing. They calculate a corrected volume (vc) using the formula:

$$vc = vo - \frac{(l-lm)(w-wm)(h-hm)}{6}.$$

There are several types of potential errors at this stage. They include: 1) inaccurate measuring by the student; 2) inaccurate recording of data; 3) having arithmetic errors, such as incorrect calculation of averages; 4) using Imperial units when determining length; and 5) recording length in millimeters, rather than centimeters.

For each specimen, students employ the formula ρ = mass/volume (v or vc) to calculate the density. Students are generally unfamiliar with the density values associated with minerals and they have no sense whether their answers are reasonable. Calculations and answers are turned in to the lab instructor. Reported densities have ranged from less than 0.4 g/cm^3 to over 13 g/cm^3. Students generally ask if their results are correct before they turn in their data and calculation sheets. The instructor indicates that will be the topic for the next laboratory session. Prior to the next lab meeting, the instructor prepares a spreadsheet and histogram for all density data organized by specimen.

Interpretation of Data – The Second Laboratory

The second session begins with a general discussion of four types of error. Gross errors, also known as personal errors (Lahee, 1961), are large, the result of a blunder. Examples are misplacing a decimal point or inverting mass and volume in the defining equation. Inversion (volume/mass) typically results in reported values less than 0.60 g/cm^3. Systematic errors (Krumbein and Graybill, 1965; Lahee, 1961) may be instrument errors, such as not taring the balance or a systematic drift in a balance. Method errors (Krumbein and Graybill, 1965), also known as errors in procedure (Lahee, 1961), involve, for example, the operator misreading the vernier scale or measuring in inches rather than centimeters. Random errors (Krumbein and Graybill, 1965) are small, giving answers both higher and lower than the truth, and tend to cancel out.

Students are given a spreadsheet and histogram based on all data turned in by the class at the end of the prior week's laboratory. Questions are raised concerning how many significant figures should be reported in each answer. This leads into a discussion of significant figures and accuracy limits (Hansen, 1999) for the measurement methods used. The class comes to an understanding that only two or three significant figures are justifiable, depending on the precision of the measuring equipment.

Next, the group focuses on the density data for a specific rock. Commonly there will be an answer of less than 1 g/cm^3. Students are told that the density of water is 1.0 and are asked if the rock floats. To drive the point home, the specimen is placed in a pan of water. Students are challenged to review and reexamine their procedures from the past week. Once they have identified unusual values, they seek to associate them with specific types of errors. If students identify certain errors, such as a miscalculation or use of inappropriate units, they correct the errors and write a rationale for the change. Rock-density results for metabasalt, after review and correction, are shown in Table 1.

After correcting the data for errant values and justifying the changes, we consider the extent to which answers are not identical and whether the distribution of answers is symmetrical. The histogram shown in Figure 1 portrays data from Table 1. Students determine a class mean and whether 67% of all data points fall within one standard deviation of the mean. Finally, the class draws a conclusion from all reviewed and corrected data as to the probable density of the material. In the example shown of the metabasalt, the class mean was 2.80, a value that compares favorably with published values of 2.704-2.852 (Daly and others, 1966).

Later Use of Density Value

Students use their density values for granite and metabasalt in three distinct contexts later in the course. The lecturer calculates the velocities of compressional seismic waves (Vc) using the relation:

$$Vc = \left(\frac{k + \frac{4}{3}G}{\rho} \right)^{\frac{1}{2}} \quad ,$$

where k is the bulk modulus, and G is the modulus of rigidity. Student-determined densities are used in the derivation. Using the equation, we calculate that the Harney Peak Granite, which has a density of 2.5 g/cm^3, has a compressional velocity of 6.0 km/sec, and the Nemo Metabasalt, which has a density of 2.8 g/cm^3, has a compressional velocity of 6.6 km/sec. Students see the application of this in the reflection that occurs at the Moho. Details of the calculation are given in Derringh, 1998.

In a subsequent lab exercise, the students are challenged to calculate the difference in elevation between continental masses and ocean basins that results from the differences in density between the continental crust and the oceanic crust. This exercise has been adapted from Exercise IIA/Staying Afloat: Continents and ocean basins (Bjϕrnerud, 1999).

In another lab exercise, students use their values of density for pure quartz and the three sandstones in a laboratory exercise to calculate porosity. We assume that the pores in the sandstones are filled with air. Porosity, a unitless value expressed in percent, is calculated for each sandstone using the equation:

$$\frac{\rho \text{ quartz} - \rho \text{ sandstone} \times 100}{\rho \text{ sandstone}} \quad .$$

Students use their density values for massive quartz (2.54 g/cm^3), for Lakota Sandstone (1.85 g/cm^3), for Deadwood Sandstone (2.07 g/cm^3), and Vermillionville Sandstone (2.24 g/cm^3) to calculate sandstone porosities of 43.2%, 28.0%, and 29.9%, respectively. A discussion leads to recognition that the Lakota is weakly cemented with silica, the Deadwood is strongly cemented with silica, and the Vermillionville has a clay matrix. Students are asked which rock can hold the most water. Because of their familiarity with the "gallon," students are informed that a cubic foot of water is 7.5 gallons, and they are asked to calculate the amount of water contained in a cubic foot of each sandstone. The answers are 3.24 gal/ft^3, 2.10 gal/ft^3, and 2.24 gal/ft^3, respectively. See Derringh, 1998, for more on this approach to calculating porosity using rock density.

Discussion

The property of density, as shown in this paper, provides significant opportunities for building quantitative skills of beginning college students. The 13% of our available lab time devoted to the determination of density and the consideration of errors in its measurement is well spent, based upon remarkable performance of students in short essay exams. We ask students "what is density," and to "define porosity." On a basis of 5 points, virtually every student scores 4 or 5. Students tell us that they enjoy these exercises, and the lab instructors recognize moments of discovery among the students.

Conclusions

Students enjoy the learning process they experience in these exercises on rock density. They integrate physical measurements and think about testing and correction of results. Of particular value, in our view, is the continuity involved in bridging from minerals, rocks, and density to seismic velocity, isostasy, and porosity.

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About the Authors

Robert S. "Skip" Nelson is active in the planning and implementation of General Education at I.S.U., having created the course *Principles of Geology*. He represents the natural and physical sciences on the General Education Coordinating Committee. His academic training was at Augustana and the University of Iowa. His disciplinary interests are in geomorphology and environmental geology, and his current research involves mechanical properties of unconsolidated sediments.

Robert G. Corbett serves as Department Chair at ISU and has been active in geoscience education. He is chair of the American Institute of Professional Geologists' Academic Education Committee and is involved with evaluation of college geoscience programs. His academic training was at Harvard and the University of Michigan. In the discipline, his focus is on the geochemistry of meteoric waters, and current research involves the chemistry of rain water.