MEASURING THE DENSITY OF ROCK, SAND, TILL, ETC.

1 Summary

For measuring the density of a variety of geological materials, in particular oddly shaped samples of relatively consolidated material. Density is important in the context of cosmogenic-nuclide measurements because the cosmic ray flux is attenuated according to mass depth below the surface, i.e., it's necessary to think of depth of overburden or sample thickness in $g \cdot cm^{-3}$, a unit of mass per square area, rather than simply in length. This quantity is generally called 'mass depth' and is equal to $z\rho$, where z is depth below the surface and ρ is the integrated density of overlying material between the surface and depth z. In order to compute this, you need to measure the density of your sample and/or its overburden. This document describes methods for doing this.

1.1 Version

This version prepared November 2003 by Greg Balco. Available at:

http://depts.washington.edu/cosmolab/chem.html

1.2 References

Most of these methods are standard and can be found in any geological or soil science manual.

If you use the data, measurements, or conclusions in this document, however, please cite it as follows:

Balco, G. and Stone, J.O., 2003. Measuring the density of rock, sand, till, etc. UW Cosmogenic Nuclide Laboratory, methods and procedures. *http://depts.washington.edu/cosmolab/chem.html*

The glass bead method is not commonly described in manuals. We got the idea from Sheldrick (see below) and adapted it for our purposes. If you use it, please also cite:

Sheldrick, B.H., ed., 1984. Analytical methods manual 1984. Land Resource Research Institute, Research Branch, Agriculture Canada. *http://sis.agr.gc.ca/cansis/publications/manuals/analytical.html*

2 Methods

2.1 A note on collecting samples

The idea of this whole procedure is to determine the density of the material in its natural condition. Thus, the most important thing is to try to get the sample to the measurement without disturbing it too much. If you can, measure the density in the field. For weakly consolidated material, try to collect the sample in some sort of rigid holder so it won't be crushed during transport. For wet material, seal samples in something watertight so that water will not evaporate before you measure their density. Try to collect multiple samples, and try to make the samples representative. In general, larger samples are better.

2.2 Collecting a known volume in the field – unconsolidated sediment

In principle, it should be easy to measure the density of any material by cutting out a cube of the material, measuring the size of the cube to determine its volume, and then weighing the cube. In practice, it's nearly impossible to cut out a regular cube of any natural geological deposit.

For some unconsolidated sediments, it is possible to collect a known volume in the field. This works well for wet sand and silt. It sometimes works for glaciolacustrine sediment and wet, clay-rich glacial till. It generally doesn't work for gravel, dry sand and silt, or anything cemented. The preferred device is a section of aluminum pipe several inches long. It's helpful if the edges of the ends of the pipe have been beveled on the outside to make a sharp edge. The procedure is as follows:

1. Determine the volume of the pipe section by accurately measuring the inside diameter and length of the pipe. Measure as accurately as possible using calipers. If the pipe was cut by hand, measure the length at several locations around the circumference of the pipe and take the average. Determine the weight of the pipe.
2. In the field, push the pipe into the outcrop face until material starts to extrude out the near end. Hammer it as necessary. Be careful to ensure that there is no air space inside the pipe. Dig the pipe out and carefully slice the protruding sediment away from each end.
3. Weigh the pipe and sediment. It's best to bring the el-cheapo balance into the field with you and do this on site. If this is not possible, wrap the sample by placing something hard over either end (proper pipe caps are best) and then saran-wrapping and taping the whole thing to minimize water loss during transport. When disassembling it in the lab, make sure that all the sediment in the tube gets weighed and doesn't fall out during cap removal, etc., or that you weigh the tube, sediment, and caps together and then the caps separately.
4. Subtract the weight of the pipe (and caps) from the total weight to determine the sample weight. Divide by the pipe volume to get the density.

It's good to do this a few times for each unit. The most important thing is to get the pipe entirely full of sediment.

2.3 Non-porous samples - weighing in water

The second easiest way to measure the density of material is to weigh it in air and then in water. If W_a is the weight of the sample in air and W_w is its weight when immersed in water, then its density is:

$$\rho = \frac{W_a}{W_a - W_w} \tag{1}$$

assuming, of course, that your water is pure H_2O at 25°C.

This is easy to do with most modern analytical balances, which generally have a hook on the bottom connected to the load cell so that one can weigh suspended objects. In our lab, use the Scout balance. Place it over one of the strategically located holes in the lab bench. Obtain a 1-meter length of thin steel wire. Weigh it. Affix the sample to one end of the wire. This may require some creativity. Make a loop in the other end of the wire. Fish it up through the hole and place it on the hook on the balance. Read off the weight. The sample weight in air is this weight less the weight of the wire. Fill a large beaker with DI water. Raise the beaker up from beneath the sample so that the sample is immersed about 1 inch below the surface of the water. Prop the beaker on something of the appropriate height. Read off the weight. The immersed sample weight is this weight less the weight of the wire (relatively little of the wire is immersed). Calculate the density with equation (1). Remember to dry the sample thoroughly before repeating the exercise, so as not to change the dry weight.

Obviously, this method is restricted to samples that are non-porous and will not absorb any of the water in which they are immersed. In practice this means igneous and metamorphic rocks, and some limestones.

2.4 Oddly-shaped and porous, but well consolidated samples – glass bead method

This method is designed for oddly-shaped samples of at-least-somewhat-consolidated material, for example glacial till, compacted loess, saprolite, cemented sand, sandstone, shale, etc. The procedure is as follows:

1. From the top left drawer in the sediment lab, select a stainless-steel tin slightly larger than your sample. Place it in one of the aluminum baking pans. Record the tare weight W_T and volume V_T of the tin (written on the side of most of the tins).
2. Using the Scout balance, weigh your sample and record the weight W_S.
3. Pour out enough beads to fill the tin about 5 mm deep. Bed a flat side of your sample in the beads. Make sure the sample does not stick out past the rim. Fill the rest of the tin with beads, making sure to tap the tin to settle the beads into all the nooks and crannies of the sample.
4. Overfill the tin with beads, then take the steel spatula and scrape the excess beads away, filling in gaps around the edges, until the surface of the beads is precisely flat with the rim. It's important to do this exactly the same every time. Make sure to catch all the loose beads in the baking pan.
5. Weigh tin, sample, and packed beads and record the weight W_{TSP}. Dump the beads back into the baking pan. Remove the sample, trying not to break it up too much and get crud in the beads. Pour the beads from the baking pan back into the storage tin.

6. Calculate the weight of packing material, $W_P = W_{TSP} - W_T - W_S$. Calculate the volume of packing $V_P = W_P/\rho_P$. ρ_P is the density of the packing material (see below). Calculate the sample density $\rho_S = W_S/(V_T - V_P)$.
7. Do the measurement a couple of times to make sure you really did fill all nooks and crannies with the beads the first time.

Notes:

- Metal vessels work best for this. Anything plastic will cause trouble with the beads due to static electricity.
- We measure the volume of the tins by measuring the weight of water that will fit in them. It's important to make sure that the water surface is close to the actual top of the tin (to which you will grade the beads) – it's possible to overfill due to surface tension.
- We use 1-mm glass beads (available from chemical supply companies). 0.5-mm beads also work OK but are a bit messier. We determine the density of packed beads by filling a tin of known volume and measuring the weight of the beads. The density of our 1-mm beads ρ_P is 1.53 $g \cdot cm^{-3}$. It's probably a good idea for each person to independently determine bead density with their own particular scraping/compacting technique.
- Occasionally it's necessary to clean the beads. We do this by sonicating them in water, rinsing thoroughly, and drying. If a lot of large chunks of foreign material build up in the beads, sieving might be needed.
- We also use clean beach sand (mostly quartz) in the 0.5-0.85 mm size range. We prepare it by sieving the sand to this size, sonicating it in water for approx.1 hr, then rinsing it thoroughly and drying in the oven. The advantage of sand is that it is inexpensive and can be used in sacrificial applications, such as the wet density determination method described below, or when samples are very poorly compacted and are likely to break up during the process and make a mess. Sand does not compact as readily as glass beads (more angular grains), so it's very important to repeatedly tap the tin containing sand and sample on the bench as you are filling it, to make sure the sand is fully compacted. Also, each batch of sand will have a slightly different density which will need to be measured before starting. Our sand has a density ρ_P of 1.45 -1.47 $g \cdot cm^{-3}$.
- By repeatedly measuring the density of a variety of samples, including large quartz crystals, whose density, of course, we know exactly, we've determined the accuracy/precision of this technique to be $\pm$ 0.08 $g \cdot cm^{-3}$ for typical materials with densities of 1.2 - 2.7 $g \cdot cm^{-3}$.

2.5 Unconsolidated samples – stuffing into a vial

If the sample is completely unconsolidated, e.g. dry sand, there is one method remaining. Take a vial of known volume, for example one of the small metal tins or plastic vials in the drawer. Using your fingers, press the sample into the vial, attempting to duplicate the natural compaction of the material. For most sands, this means squishing it in with some authority to ensure that the sand grains are well packed. Overfill the vial and blade off the excess with the steel spatula. Weigh sample and vial, subtract the tare weight of the vial, and divide by the volume of the vial.

Despite the *ad hoc* nature of this technique, it probably does a fairly good job of measuring the density of sandy surficial sediments, because relatively well-sorted sand reaches its maximum compaction quickly and then does not compact any further until buried really deeply, like kilometers. This would also be the only way to measure the density of unconsolidated fluvial gravels, but the vessel would have to be much bigger, in keeping with the grain size of the gravel, to ensure a representative sample.

2.6 Notes on wet vs. dry density

In reality, most geological materials are water-saturated below a few meters depth in most environments. However, in many cases, especially when working on drill core, the only samples available to measure overburden density have been dried during storage. Thus, we need some means of converting dry to wet density. The wet density of samples which are collected dry can be approximately measured by the following procedure:

1. For unconsolidated samples, pack a vial of known weight and volume with the sample as described in 2.5. For consolidated samples, pack a tin of known weight and volume with sample and packing material as described in 2.4. The packing material will be inseparable from the sample at the end of this procedure, so we suggest using sand as described in the notes to 2.4 above. Record the relevant weights.
2. Add distilled water to the vial or tin slowly and carefully until everything in the tin is completely saturated. Leave the sample to soak for at least 24 hours to ensure that well-compacted samples become fully saturated. For large samples of glacial till or the like, you may want to let them soak for a couple of days. Periodically add water to keep the sample fully saturated. When you are satisfied that the sample is fully saturated, record the total weight of vessel and contents.
3. For unconsolidated samples, subtract the weight of the vial from the total weight to obtain the wet weight of the sample, then divide by the volume of the vial to determine the wet density.
4. For consolidated samples, you have just measured W_{TSPW}. Calculate the total weight of water added $W_{WT} = W_{TSPW} - W_{TSP}$. Calculate the weight of water incorporated in the packing material $W_{WP} = V_P f_{WP} \rho_W$, where f_{WP} is the water content of saturated packing material (see below) and ρ_W is the density of water, i.e. 1 $g \cdot cm^{-3}$. Calculate the wet weight of the sample $W_{WS} = W_S + (W_{WT} - W_{WP})$. The wet density of the sample ρ_{wet} is then W_{WS}/V_S.

Our quartz sand has a saturated water content f_{WP} 0.45 by volume (0.24 by weight), which equates to a wet density of 1.90 $g \cdot cm^{-3}$.

This method is not always accurate, primarily due to the tendency of many materials that contain clays to expand when wet, but is often the only option for determining the wet density of dry material obtained from old, cruddy drill core. It is always better to collect samples at natural moisture conditions in the field.

In addition, this method is somewhat time-consuming. A simple alternative is to assume that all of the grains in the sample are composed of quartz ($\rho = 2.65$ $g \cdot cm^{-3}$), and that all the pore space is filled when wet. Under these assumptions:

$$\rho_{wet} = \left(1 - \frac{\rho_{dry}}{\rho_{quartz}}\right) + \rho_{dry} \quad (2)$$

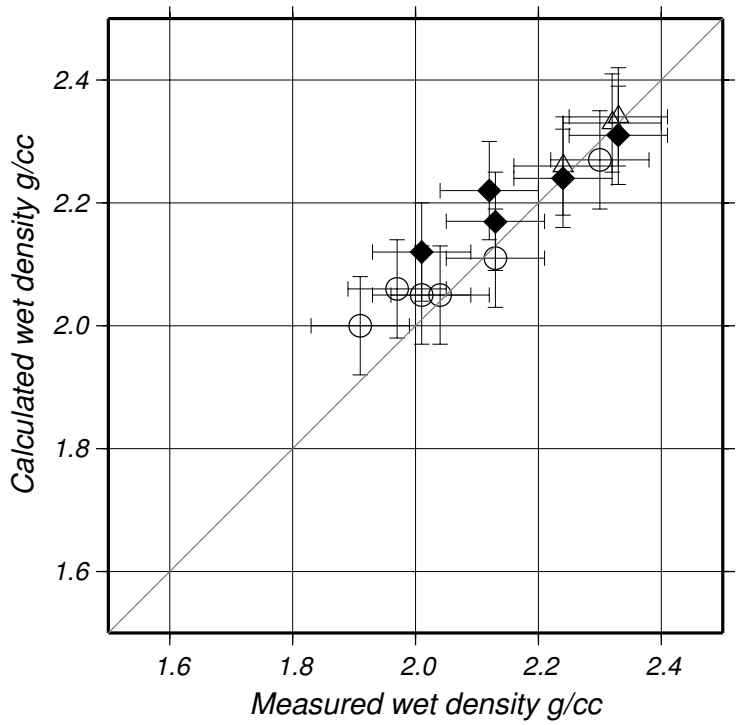

Figure 1: Measured wet densities compared with those calculated from dry densities using 2. Circles, wet density determined by saturation of dry sand, and triangles, of dry till, as described in 2.6. Diamonds, samples of glacial till collected wet and then oven-dried. Error-bars reflect what we believe to be measurement precision as described in 2.4.

We tested this approximation with samples of unconsolidated sand and glacial till that we obtained from dried drillcore and whose wet density we measured as described above, as well as with samples of glacial till that were collected wet and whose density we measured before and after oven-drying (Figure 1). The results show that this approximation seems to be adequate within the resolution of our measurement technique.